Journal

of

The Franklin Institute

DEVOTED TO

SCIENCE AND THE MECHANIC ARTS

VOL. 190.—Nos. 1135–1140
(95th YEAR)

JULY-DECEMBER, 1920

THE AUDION—ITS ACTION AND SOME RECENT APPLICATIONS.*

BY

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ANALOGIES are apt to be interesting, and in scientific matters frequently instructive and clarifying. The title of to-night's paper, "The Audion," suggestive of *Sound,* prompts the consideration of an analogy in the realm of *Sight*—the microscope. The audion, in a measure, is to the sense of sound what the microscope is to that of sight. But it is more than a magnifier of minute sounds, electrically translated; the audion magnifies and translates into sensation electric energies whose very existence as well as form and frequency, would but for it remain utterly unknown. As the microscope has opened to man new worlds of revelation, studies of structure and life manifestations of natural processes and chemical reactions whose knowledge has proven of inestimable value through the past three generations, so the audion, like the lens exploring a region of electro-magnetic vibrations but of a very different order of wave-length, has during the scant thirteen years of its history opened fields of research, wrought lines of useful achievement, which may not un-

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* Presented at a joint meeting of the Section of Physics and Chemistry and the Philadelphia Section, American Institute of Electrical Engineers, held Thursday, January 15, 1920.

fairly be compared with the benefits from that older prototype and magnifier of light waves. But when the first steps were taken in the work, which eventually resulted in the audion of to-day, I no more foresaw the future possibilities than did the ancient who first observed magnification through a drop of water realize the present application of the high-power microscope to bacteriology.

In 1900, while experimenting with an electrolytic detector for wireless signals, it was my luck to be working by the light of a Welsbach burner. That light dimmed and brightened again as my little spark transmitter was operated. The elation over this startling discovery outlasted my disappointment when I proved that the unusual effect observed was merely acoustic and not electric. The illusion had served its purpose. I had become convinced that in gases enveloping an incandescent electrode resided latent forces, or unrealized phenomena, which could be utilized in a detector of hertzien oscillations far more delicate and sensative than any known form of detecting device.

The first " commercial " audion, as it originally appeared in 1906, was therefore no accident, or sudden inspiration. For failing to find in an incandescent mantel the genuine effect of response to electrical vibrations I next explored the bunsen burner flame, using two platinum electrodes held close together in the flame, with an outside circuit containing a battery of some 18 volts and a telephone receiver. See Fig. 1—the form used in 1903. Now when one electrode was connected to the upright antenna and the other to the earth, I was able to clearly hear in the telephone receiver the signals from a distant wireless telegraph transmitter. The resistance of this new "flame detector" was decreased when the flame was enriched by a salt. Next the incandescent gases of an electric arc were considered; and likewise the action in the more attenuated gases of an ordinary lamp bulb, surrounding an incandescent filament or filaments.

But during these early years I was afforded little time to concentrate on this laboratory problem, and it was not until 1905 that I had opportunity and facilities for putting to actual proof my conviction that the same detector action which had been found in the neighborhood of an incandescent platinum wire, or carbon filament, in a gas flame existed also in the more attenuated gas surrounding the filament of an incandescent lamp. In

one case the burning gases heated the electrodes; in the other the electrodes heated the remanant gases. But in both it was *first* the electrons from the hot electrodes, and *second* ionization of the gases which these electrons produced, which established an electrically conducting state, extraordinarly sensitive to any sudden change in electrical potential produced on the electrodes from some outside source.

Considering therefore this actual genesis of the audion it will be seen that it was never, strictly speaking, a *rectifying* device. True both electrodes were seldom alike and a " polarization " was always had from the outside battery, but any rectification of the alternating currents impressed on the detector was merely inci-

Fig. 1.
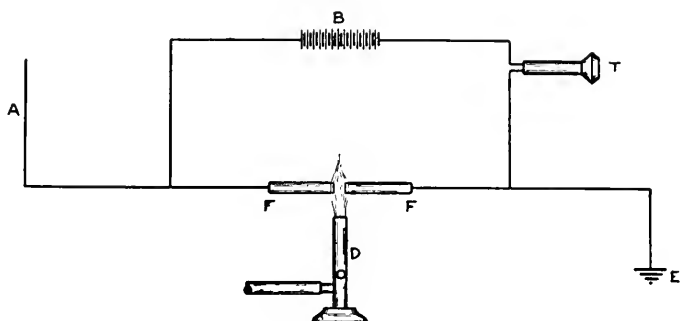
dental and played no vital part in the action of the audion. From the beginning I was obsessed with the idea of finding a *relay* detector, in which local electric energy should be controlled by the incoming waves–and not a mere manifestation of the electrical energy of the waves itself. Hence it was that the external battery as a source of local energy was always employed, when the incandescent filament was utilized as source of the electric carriers through the gas. The battery for lighting the filament I was styled the "A" battery and, as distinguished from this, the other battery was named the "B" battery. This nomenclature has been retained, and is to-day commonly accepted, even by the many who for various reasons refuse to recognize the name " audion."

At the period now under consideration, 1903–05, I was familiar with the Edison effect and with many of the investiga-

tions thereof carried on by scientists, Prof. Fleming among others. In 1904 I had outlined a plan of using a gas heated by an incandescent carbon filament in a partially exhausted gas vessel as a wireless detector, in place of the open flame. But here the rectification effect between hot filament and a cold electrode was not considered. Two filaments, heated from separate batteries would give the desired detector effect equally well. What I had already found in the flame detector, and now sought in a more stable and practical form, was a constant passage of electric carriers in a medium of extraordinary sensitiveness, or tenuity, which carriers could be in any conceivable manner affected to a marked degree by exceedingly weak electrical

FIG. 2.
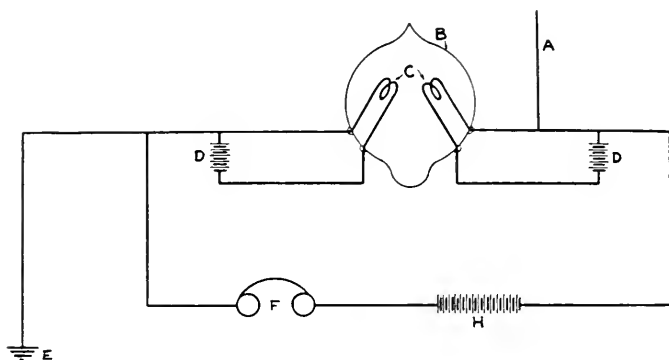
impulses, delivered to the medium, indirectly or through the hot electrodes. Fig. 2.

The ordinary small incandescent lamp of that epoch supplied admirably the conditions I required, merely by the introduction of a second electrode. That added electrode could be either hot or cold. Obviously therefore, use it cold, avoiding thus the unnecessary battery. Then obviously, too, I must so connect my telephone "B" battery as to make this cold electrode positive, for otherwise no local current could flow through the gaseous space in the lamp between the unlike electrodes. Fig. 3.

The high frequency impulses to be detected were, as in the earlier flame type, originally applied directly to these same two electrodes. That these alternating electric currents were thereby rectified was merely incidental. A glance at the plate-current, plate-voltage curve (Fig. 4), shows why, even were both anode

and cathode hot, the receipt of a train of high-frequency current
waves would produce a resultant change in the normal telephone
current and result in a signal. This typical curve, taken from a
"gasey" lamp, such as I first employed, is curvilinear over two

FIG. 3.
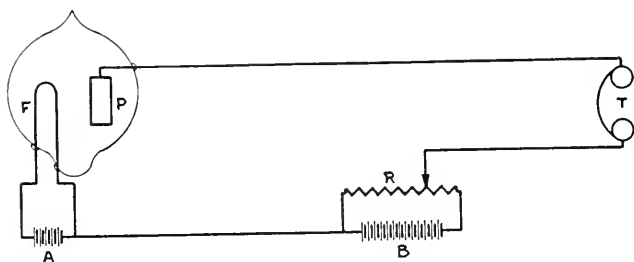
portions. If now the "B" battery potential was so adjusted that
the detector was operating on either knee of this curve the in-
crease to this locally applied voltage, resulting from the positive
halves of the wave-train, would produce a greater (or less)

FIG. 4.

PLATE VOLTAGE

PLATE CURRENT
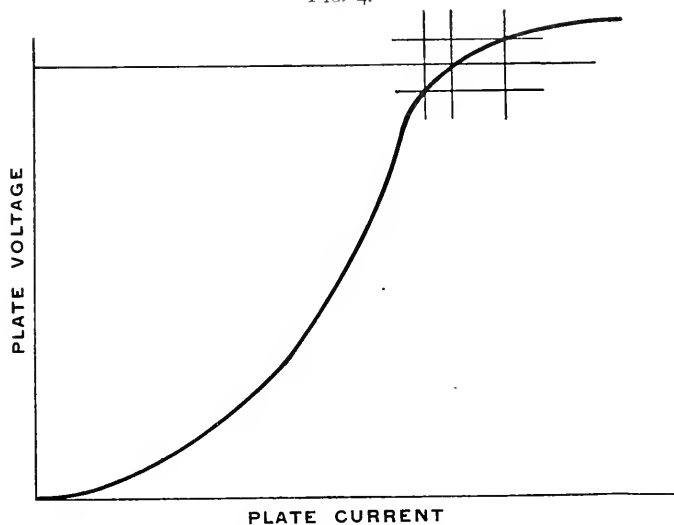
increase in the local current flowing across the gap than would
the negative halves of the wave-train produce a decrease (or in-
crease, as the case might be).

In other words, the responsive action of this two-electrode

audion was due to the asymmetry of its characteristic curve, rather than to its rectifying property. This latter property could be made to aid, to increase the intensity of the signal produced originally and mainly by the so-called "trigger," or genuine *relay* action of the device, which was always *controlling* the local energy by means of a much smaller income energy.

In others words, then, the two-electrode audion, with A and B batteries, was not primarily a "valve." And I have always objected to this misapplication of the name *valve* to the audion; a name which our British friends have from the first persisted, with a stubbornness worthy of a better cause, in misapplying!
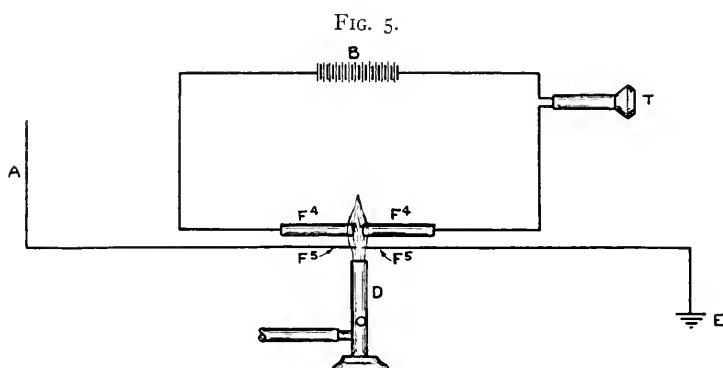
Long before the two-electrode relay audion of 1905 had a

Fig. 5.

chance to prove its worth in commercial wireless service I had found that the influence of the high-frequency impulses could be impressed to better advantage on the conducting medium from a third electrode. In its first inception the third electrode also dates back to the flame detector of 1903. Fig. 5, taken from the earliest patent of the audion group, shows the original idea of keeping the high-frequency current path distinct from that of the local telephone current. Consequently when in 1906, having secured the maximum efficiency from the two-electrode vacuum type, I cast about for further means of improvement, it was but natural to revert to this plan of separating the two circuits. The new electrode connected to the high-frequency secondary circuit was at first applied to the outside of the cylindrical lamp vessel; the other terminal of the secondary circuit was led to one terminal of the lamp filament. Fig. 6, of a 1906 patent, shows this pro-

genitor of the third electrode. This simple arrangement proving
a step in advance, I concluded that if this auxiliary electrode
were placed within the lamp the weak charges thereto applied
would be yet more effective in controlling the electron-ionic cur-
rent passing between the filament and plate.

FIG. 6.
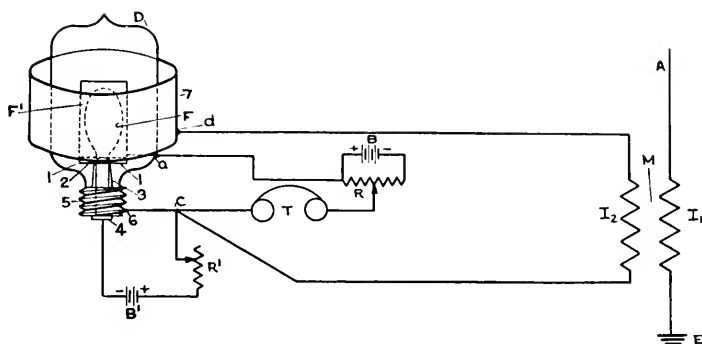
Fig. 7, taken from a patent filed two months after the preced-
ing one, illustrates the next arrangement tried. Here I used two
plates, one either side of the filament—one in the telephone
circuit, the other in the high-frequency circuit associated
with the antenna. It will be noted also that here for

FIG. 7.
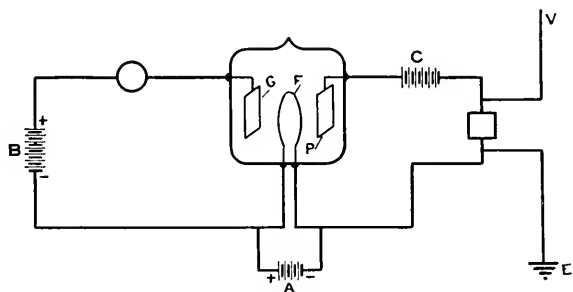
the first time was shown the third, or "C" battery, in the
input circuit, so much employed of late, notably when the audion
is used as amplifier of telephonic currents. This two-plate de-
vice proved another decided step forward, and I realized then
that if this third electrode were placed directly in the path of the
carriers between the filament and plate anode I would obtain the

maximum effect of the incoming impulses upon the local current flow. But obviously another electrode thus placed directly in the stream must not be a plate—it must be perforated to permit the carriers to reach the anode. A wire bent back and forth in form of a grid should answer admirably. Fig. 8, taken from the patent filed in January, 1907, the so-called "Grid Audion" patent, illustrates the preferred form which the idea promptly assumed.

In surveying the wide field of electric communication to-day one cannot look back at that little figure, of the first grid electrode, without a sense of wonder at the enormous changes which it has wrought. It has made possible *commercial* trans-oceanic radio telegraphy. It has realized trans-Continental telephony:

FIG. 8.

it has made reception of wireless signals half-way around the globe an everyday occurrence. The uncanny accuracy of millions of shells from the Allies' guns, the clock-like precision of advancing barrages, would have been impossible save for the effectiveness of their trench and airplane radio service, in which the grid audion was the essential heart. To-d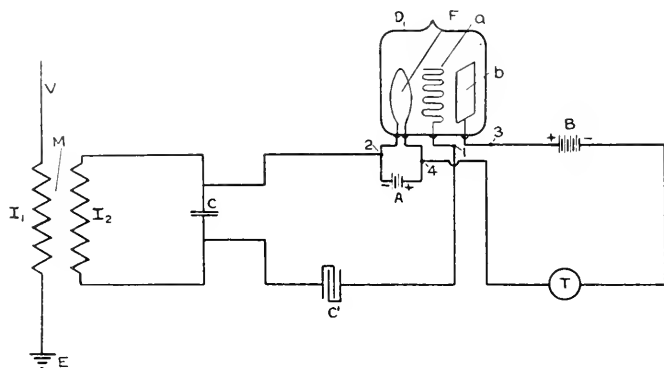ay this little grid controls and modulates an ever increasing kilowattage of radio telephone energy, which as early as 1915 conveyed the spoken voice from Arlington to Honolulu, and more recently from New Brunswick to the transport *George Washington*, in the harbor of Brest. It has already placed twenty simultaneous telephone messages upon a single pair of wires. A few ounces of grid wire make possible the saving of hundreds of tons of copper in long distance telephone conductors. It has given to the physicist

a tool for the exploration of unprobed fields of research; and to the electrical engineer a generator, without moving parts, of alternating currents of any desired frequency, from one to ten million period per second—a machine absolutely constant and reliable in its silent work.

Let us consider briefly the explanation of all this radical advance, the theory of the invisible mechanism whereby this astonishing control of powerful energies by minute impulses is effected. Lacking a very concrete conception of just what electrons are and just how electric charges residing on a grid can so effectively dam back the flood of electrons expelled at enormous velocities from a hot cathode at the urge of high potentials—our minds must be content with pictures of characteristic curves and mathematical formulæ, at best but crudely interpretive.

The fundamental operating characteristic of the audion is that expressing the current flowing from filament to plate in terms of the potentials supplied to the grid. Fig. 9 expresses this relation graphically. Here we see that a moderate negative potential (10 volts) applied to the grid completely cuts off the current between filament and plate. As this negative grid charge is reduced to O the plate current rapidly increases. As the grid potential becomes positive this plate current continues to increase up to a point S, after which it rapidly approaches a saturation value, above which the plate current will not rise, regardless of how high is the positive potential applied to the grid. This curve was taken with a given fixed potential difference applied between filament and plate, and for a given filament temperature. This sample characteristic was taken from a "hard" audion, from which the gas has been sufficiently well exhausted to show no irregularity in its curve, due to ionization. It will be observed that over the straight line portion of this curve, between points Q and S, when the grid potential varies a small but equal amount on right and left of zero, the amplitude of variation in the plate current is directly dependent on the variation of the applied grid potential. In other words, there will be over this range no distortion between the wave form of the incoming alternating potential impressed on the grid and that of the current fluctuations produced in the plate, or output, circuit. Obviously therefore the straight line portion of the audion characteristic is the one to utilize in an audion amplifier, or repeater.

whether for amplifying radio or voice-frequency currents. Consequently we find telephone engineers going to extreme lengths to so design their audions and circuits, and to so regulate the potentials applied to the grid, as to operate entirely within this straight line characteristic. The result is a perfect reproduction of voice currents, but magnified to any extent desired by the use of two or more such amplifiers connected in cascade—from ten to twenty thousand times or more.

But when the audion is used as a simple detector of damped radio signals, where it is desired to obtain the maximum possible integrated effect from a train of incoming high-frequency waves

FIG. 9.

POTENTIAL OF GRID WITH RESPECT TO
NEGATIVE END OF FILAMENT
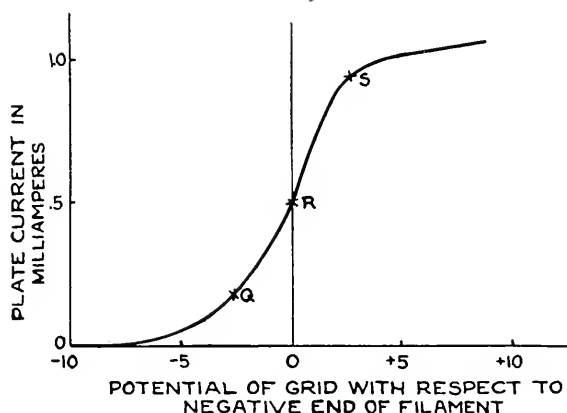
upon the direct current in the plate circuit, it is desirable to operate at the lower, or upper, knee of this characteristic curve, for the reason already explained. Here we have taken advantage of the asymmetry of the curve, so that the sum of the decreases in the plate current as the grid potentials decrease, greatly outvalues the sum of the increases in the plate current, when the grid potentials increase. This results in an integrated decrease in the current through the telephone receiver, which may represent much greater energy than that of the incoming wave-train.[1] It is thus that the audion can operate as a true *relay* device, possessing a sensitiveness far greater than that of the most perfect crystal rectifier, or of any valve. Consideration of the advan-

[1] Where a " C " battery is employed for keeping the grid always negative, the audion is operated on the lower knee of its characteristic curve.

tage of thus working on the asymmetric portion of the audion curve would lead us to expect an increase in sensitiveness as a detector of spark signals if this asymmetry be further emphasized by the introduction of a small amount of gas into the bulb, thus producing a very appreciable amount of ionization. Such has long been known to be a fact—no high vacuum audion to-day equals, as a radio detector, the "soft" bulbs which were in very general use a few years ago. The presence of such an amount of gas is usually evidenced by a blue haze seen around the anode, when high potentials (say from 60 to 100 volts) are applied across plate and filament. Ionization phenomena always introduce certain irregularities in the operation of the audion, and kinks, or cusps, in its characteristic curves—even where the gas pressure does not greatly exceed one-ten-thousandth of a millimetre of mercury.

Our knowledge of electrons is of comparatively recent date. In 1899 J. J. Thompson showed that negative electricity is given off from a heated carbon filament in the form of electrons having a mass of 1/1800 that of a hydrogen atom. These electrons may be considered as atoms of electricity. Richardson, in 1903, first applied the electron theory of metallic conduction to emission from heated conductors. He assumed that electrons are ordinarily held bound within the metal by an electric force at the surface, by a tension similar to the surface tension of liquids. But if the velocity of an electron be made sufficiently high, as by applied heat, it is able to overcome this surface force and escape. The number of electrons, therefore, which attain the necessary critical velocity to escape will increase very rapidly with the temperature. The laws are similar to those governing the increase in vapor tension of a liquid with increasing temperature. Richardson thus concluded that the electronic emission from an incandescent metal should increase according to a similar equation:

$$i = a\sqrt{T}\, e^{\frac{-k}{T}}$$

where i is the current per square centimetre at temperature T, and k is a constant dependent on the latent heat of evaporation of the electrons. But actual investigations of the Richardson law, notably by Dr. Langmuir, showed that as the heat of a cathode filament was increased the thermionic current increased first in accord with Richardson's equation, but that beyond a certain

point further increase in temperature produced no further in-
crease in thermionic current.

A family of saturation curves, each one corresponding to a
certain applied fixed potential between cathode and anode, re-
sults, as shown in Fig. 10, where the first parts of the several
curves combine to form a single curve following Richardson's
law. These curves [2] show that the thermionic current does not
continue to increase as expected, because the space surrounding
the hot filament is capable of carrying only a certain current for
a given potential difference. The explanation offered is that the
electrons surrounding the filament soon set up a " space charge "
which repels new electrons escaping from the filament, causing
some to return to the filament.

From a study of the curve family of Fig. 10, Langmuir has
evolved a formula introducing the factor of plate potential, in the
case of a filament coaxial with a cylindrical anode. Here the
current in amperes

$$i = 14.65 \times 10^{-6} \cdot \frac{V^{\frac{3}{2}}}{r}$$

where r is the radius of the cylinder in centimetres. But ex-
tremely minute amounts of gas vitiate the correctness of this
formula by neutralizing more or less the space charge.

Therefore for a power oscillator a certain definite amount of
gas in the tube may prove a distinct advantage. The filament,
if of tungsten, has a tending to absorb gas, so that if a small
amount only is left in the tube on exhaustion the audion shows
a tendency to grow " harder " with use. A perfect vacuum is
never attained; spectrum analysis shows traces of residual gases
always present, even in the " hardest " of tubes. If powerful
bombardment of anode plates is long continued, gases will be
thereby driven out from the metal and the tube rapidly become
too soft to be of use—unless the gases have first been thoroughly
exhausted from all metal parts within the oscillion, by methods
well known to the X-ray tube art. Moreover, too much positive
ionization tends to disintegrate the cathode filament. With
negligible ionization there appears to be no disintegration of the
filament by the electronic discharge, and its life is as great as
though no electronic current flowed.

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[2] Due to Dr. Langmuir.

We have just seen, then, how the space charge surrounding
a hot cathode can, in the absence of sufficient ionization, produce
a saturated condition of the plate current. This current, or
number of electrons emitted, is fixed by the cathode temperature
for a given applied voltage, while the velocity of the electrons is
dependent on this applied voltage. These electrons, escaping
from the cathode and producing the choking space charge, can
equally well charge up a third electrode located in this space to a

FIG. 10.
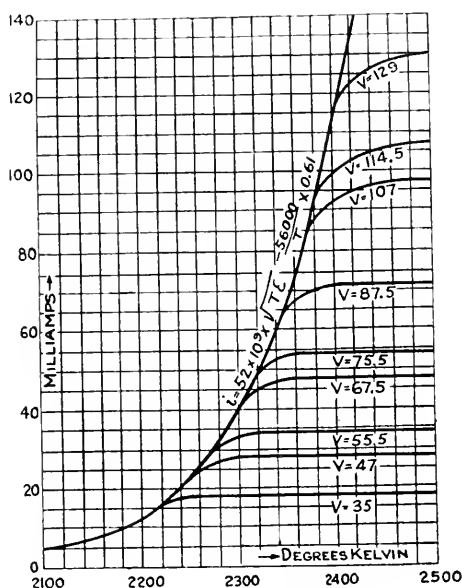
considerable negative potential with respect to the cathode. It
will be seen therefore how readily one can expect to control the
plate current by means of relatively small potentials, positive or
negative, applied to this control electrode, the grid. But the
presence of the grid between cathode and anode so complicates
the electric field distribution that a theoretical analysis of the
relation between the plate current and the plate voltage and the
grid voltage (with respect to the filament) is too complicated to
be of any practical use. Empirical formula for predetermining
the characteristics of various types of audion have been evolved.
These, unlike the greater mass of mathematical writings already

flooding this new art, are actually proving of some real help to the tube engineer.

In a highly exhausted bulb the so-called " space charge " ordinarily acts to very quickly limit the thermionic current flowing from the hot cathode to the cold anode, but the present of positive ions partly neutralizes this space charge. Now if a small positive charge be applied to the grid the velocity of the electrons passing through it is increased, and consequently they produce more ions by bombardment. Moreover, the number of electrons passing the grid is increased, which in turn again increases the ionization. If too much gas is present, permitting too large a plate current to flow, the relaying action of the audion disappears, because the grid charges are then unable to control the large ionic currents. This condition is usually evidenced by the visible blue glow. In the region between these two limits the audion may possess an extraordinary sensitiveness, as is usual with any condition of instability.

In the early days when audions were exhausted, like the ordinary incandescent lamp, by oil pumps merely, it was ordinarily impracticable to exhaust to such high vacuua as to permit the use of more than 40 to 80 volts of B potential, without producing this excessive ionization. However, in 1912, when I first began to construct larger bulbs for large amplification of telephonic currents, it became apparent that the higher voltage necessary for producing the loud amplifications desired required higher and higher potentials, which obviously necessitated higher vacuua, and better methods of exhaustion. It was then for the first time that I caused audion bulbs to be exhausted by X-ray tube methods, enabling me to apply several hundred volts of plate potential. So the perfecting of means for exhausting the bulb kept pace with the growing requirements for larger power to be handled. There was at no time in the evolution of the audion, from the original incandescent lamp vacuum to those high exhausts now necessary in the largest " power-tube," or oscillion, any definite demarkation in the degree of vacuum needed or obtained. The lamp-makers' and glassblowers' skill kept pace with the radio engineers' requirements of larger bulbs and greater amounts of energy handled.

In the earlier types of audion detector a stopping condenser in the grid lead was usually, but not always, employed. There were

then sufficient ions in the bulb to ordinarily prevent the gradual accumulation on the thus insulated grid of a large negative charge, which would very rapidly completely cut off the plate-filament current. However, when heavy static discharges struck the receiving antenna it was frequently observed that the audion would be "paralyzed" for several seconds thereafter. We early learned how to discharge this residual negative accumulation on the grid, at first merely by putting the wetted fingers across the grid and filament terminals. This primitive "grid leak" was soon made in permanent form—for example, a wet string, and later a high-resistance graphite pencil mark. As the degree of vacuum of the bulb was increased the necessity for this grid leak became more urgent, and since 1913 it has been generally ap-

FIG. 11.
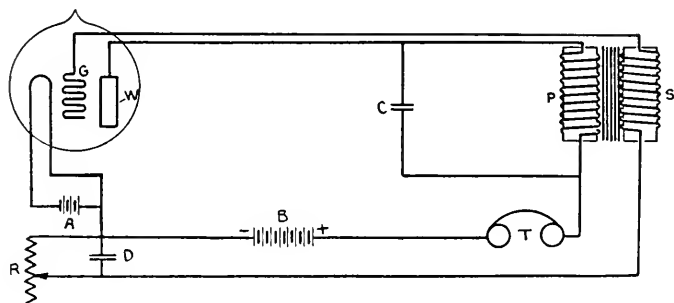
plied to all high vacuum tubes, when stopping condensers are used; whether the bulb be a detector, amplifier, or generator of alternating currents.

It was in the summer of 1912, when at work on the problem of audion amplifiers in cascade arrangements for telephone repeaters, that I first discovered that if the input, or grid, circuit was inductively coupled with the output, or plate inductance, the audion became a generator of continuous alternating currents, originally made evident by a shrill tone in the telephone receiver. A typical regenerative circuit is illustrated in Fig. 11. The explanation of the operation is simple. An initial impulse in the plate circuit, however produced, induces a similar one in the grid circuit, which, if of proper polarity, will impress on the grid a sudden change in potential which may in its turn produce an impulse in the plate current in the opposite direction to the origi-

nal disturbance. This reaction then becomes self-sustaining, provided the resistance and hysteresis losses in the two circuits are not too great; and the amplitude of the oscillating current thus set up goes on increasing, taking energy supply from the B battery, until the losses in the circuits equal the increment of energy drawn from the battery. Whereafter an alternating current of perfectly constant amplitude and wave form is maintained. The frequency of this alternating current depends on the constants of the circuit, the inductance and capacity in the input or output circuits. But under certain conditions it depends to some extent also on the resistance in the grid leak, if this be used, and sometimes, but not usually, on the temperature of the filament and the B voltage.

A few months after this type of circuit was first used for the production of alternating currents of audible frequency I first demonstrated the fact that weak *high-frequency* currents could equally well be generated, simply by substituting radio-frequency coils for the original iron-cored coils, and small variable air condensers for the large telephone condensers of the original experiment. And quite naturally, also, since I was at the time engaged chiefly in work on undamped wave radio transmission, this generation of radio frequency waves was first demonstrated in receiving heterodyne, or more exactly autodyne, signals. The circuit used at this early date, April, 1913, which was almost identical with that in Fig. 11—Fig. 12, shows the usual antenna receiving circuit, the usual secondary circuit connected across the grid and filament of the audion, but with another coil similar to the secondary in series with the telephone receiver, which in this case was abridged by a small condenser.

In the fall of that year my assistant, Mr. Longwood, and I discovered, largely by accident, that if the secondary receiving circuit be connected across the grid and plate, instead of as customary between the grid and filament of an audion, the circuit became a persistent oscillator, very simple and effective as a receiver of undamped wave signals. On account of the great sensitiveness of this combination the name " ultraudion " was applied to it. Countless modifications and adaptations of these two general types of oscillating audion circuits have been developed by radio men here and abroad. For their simplicity, the ease with which all the advantages of the beautiful heterodyne prin-

ciple of Prof. Fessenden and Vreeland can be realized, the clarity of note and range of pitch which the receiving operator can instantly command—coupled with a degree of sensitiveness of a different order from that of any other type of detector—these advantages very quickly relegated to the scrap-heap the ticker and tone-wheel; and at once placed the transmission by undamped waves upon an altogether different level from that of the older spark methods.

But the audion in an oscillating or an almost oscillating, or unstable, condition is also of great utility in detecting damped wave signals, or even radio telephone currents. If the two cir-

FIG. 12.
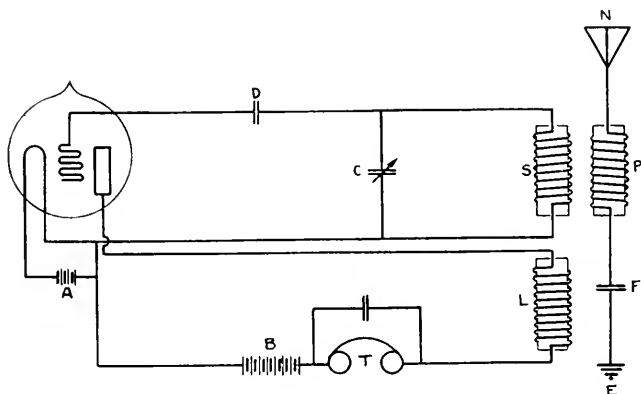
cuits, input and output, are so separated as to interact less energetically the oscillations become weaker and finally just cease to be generated. When in this condition a very feeble impulse, if properly attuned, can set the system into vibration. The resulting response develops an energy almost unrelated to the cause. Enormous magnifications are thus possible with a single audion, and spark signals have thus been received over the greatest span which it will ever be possible to reach on this earth—half way around the globe.

In receiving undamped wave signals, when the local oscillating receiver circuit is slightly out of tune with the incoming waves, the received currents on reaching the grid are amplified, first by the ordinary processes of the audion, and then combine with the local oscillations to produce " beat " notes, of audio-

frequency, which beat note currents are themselves amplified by
the audion, before delivery to the telephone receiver. So sensi-
tive is the pitch of this beat note to the slightest change of capacity
or inductance in the circuit (when very high frequencies are em-
ployed) that in properly designed circuits a change of capacity
of one-thousandth part of the electrostatic unit can be detected.
A change of capacity which is caused by substituting coal gas
for air in a condenser can thus be easily measured. Similarly can
be demonstrated slight changes in resistance with temperature of
conductors, the conductivity of flames, the permeability of
liquids, etc. Very recently Prof. Blondel has utilized the audion
in a balanced bridge method for measuring excessively slight
differences in static potentials.

The uniform generation of electrical oscillations in a circuit
by means of an audion is one of the most striking and fascinat-
ing of its applications. If these are of radio-frequency there is
no sensible manifestation of their presence, but if of audio-fre-
quency the telephone receiver or " loud speaker " reproducer may
be made to give forth sounds from the highest pitch or volume
to the softest and most soothing tones. Such wide range and
variety of tone can be produced from suitably designed singing
circuits that a few years ago I prophesied that at some future time
a musical instrument, involving audions instead of strings or
pipes, and batteries in place of air, would be created by the
musicians' skill.

But lower frequencies, even to one oscillation per second, can
be obtained from the audion. Pulsations suitable for submarine
cable signalling, or for chronograph and time-pendulum work,
can be had of remarkable constancy and reliability, free from all
difficulties of speed regulation of motors, or of any moving parts.
Or a combination of mechanical time-factors, and the electrical
properties of the audion can be advantageously employed. For
example, a tuning fork may be driven by electro-magnets, one
connected in the grid circuit, the other in a plate circuit, as shown
in Fig. 13.

The movement of the grid prong here induces an e. m. f. on
the grid, which in turn controls the plate current through the
other coil acting upon the other prong of the fork, thus sustaining
its motion. If the two coils here shown are also closely coupled
inductive reaction, or regeneration, is added to the mechanical,

and very powerful vibrations may be thus set up. Various modifications of this principle will suggest themselves to physicists, who desire sparkless generation of low frequencies of great constancy. Tuned relays, highly selective to definite frequencies, and where it is desirable to reduce the damping to zero or nearly zero, can thus be constructed. The above arrangement is due to Messrs. Eccles and Jordan.

A modification of this method of linking the audion with mechanical motion is the magnetic pendulum, actuated by the plate currents through electro-magnets and inducing in another coil properly tuned impulses which, if conveyed to the grid, control through almost senusoidal currents the successive pulls upon

FIG. 13.
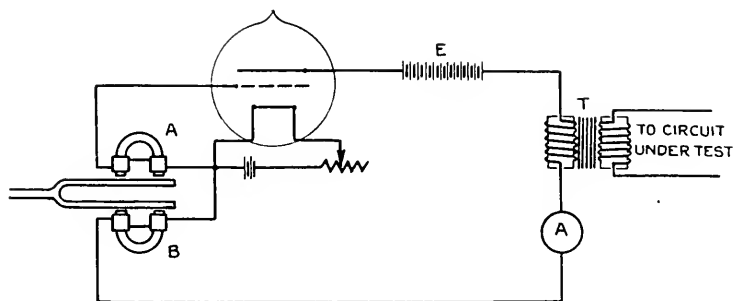
the pendulum (Fig. 14). When a second system identical with the first, but located at right angles thereto, is employed, the pendulum will be set into conical vibration, circular or elliptical as desired, and a revolving electric field will be produced, which can also be made to drive an armature or magnetized wheel at a certain definite speed.

There seems to be in fact no limit to the number of applications to which this three-electrode vacuum tube can be applied as a tool in the hands of the experimental physicist. Of especial value is the fact that it renders easily available devices having *negative electrical resistance*, as in the four-electrode device of Dr. Hull (styled the " dynatron ")—or its equivalent in some mechanical form. For one fundamental property of the audion is that an electrical influence in one circuit may, through the grid, be made to produce effects in another circuit without appreciable reaction. For the energy absorbed by the control electrode may

be considered negligible—frequently less than that required in moving a galvanometer needle.

Then, and probably the most promising field of all, the arrangement of audions in cascade as amplifiers, of pulsating currents of any form or frequency—opens to the ear what the microscope has given to the eye—new regions of research in numerous and diversified fields, from physiology, for heart beats and breath sounds—to chemistry, where some even predict that we shall some day hear " the collision of individual atons with one another." During the war British army engineers used as many as nineteen audion bulbs in cascade circuit, amplifying preferably

FIG. 14.
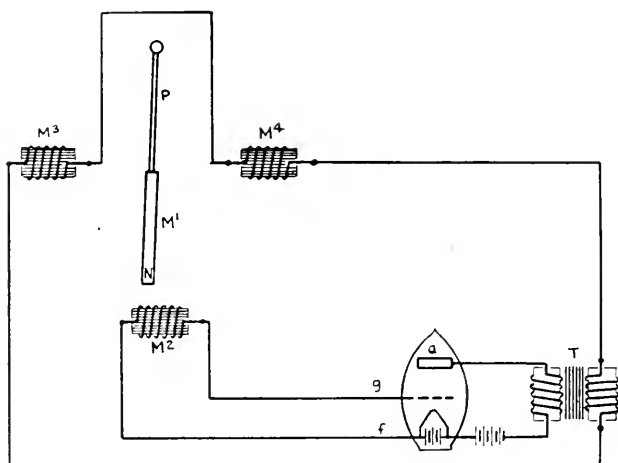
the radio instead of the audion frequency currents. With such a series it is possible to detect with certainty alternating currents of one-ten-thousandth-millionth of a volt on the input grid—involving magnifications of the order of twenty thousand times. It is an everyday occurrence now to receive radio messages from Norway or Honolulu, on a closed-loop antenna one metre in diameter, using three or more audion amplifiers in cascade between this antenna and the detector, and sometimes a similar multi-stage amplifier for audio frequencies, between the detector and the telephone receiver.

Principles which though long understood were impossible of application to radio signalling have been made realizable by the

audion amplifier, and the scope and value of the new art immeasurably increased thereby.   For example, the use of underground receiving antenna, the direction-finder, or radio-compass loop, the elimination of static interference by either of the above, or other methods—all such were compelled to await for their successful application the introduction of the grid electrode.   Starting with the small bulb used in 1912–13 as a telephone amplifier and generator of minute electric oscillations for heterodyning purposes, I began the construction of larger sizes to be used in undamped wave transmission.   At first spherical bulbs, three or four inches in diameter, and taking 50 watts of plate input energy, were considered large.   Such rapid progress was made in improvement of design and construction of these so-called " power tubes," notably by the engineers of the Western Electric Co., that by autumn of 1915 a bank of several hundred tubes, their input and output electrodes connected in parallel, were installed at the Arlington wireless station.   By a pyramidal circuit arrangement, whereby one oscillion tube controlled a group in parallel, these in turn controlling larger groups of oscillion tubes, some twelve kilowatts of undamped wave energy was delivered to the great antenna, all perfectly controlled or modulated by an ordinary telephone microphone.   By this arrangement the voice was transmitted that year as far as Honolulu and Paris, thus fulfilling predictions made in 1909 to a very skeptical world.

In these Arlington tests the entire system was one of three-electrode tubes—for power generator, for current modulation thereof at the transmitter, and for detector and amplifier at the receiver.   More recently Alexanderson, using his powerful high frequency alternator at New Brunswick, has controlled 80 kilowatts of antenna energy by means of his magnetic amplifier. This ingenious development of a Fessenden device was in turn controlled by a bank of large audion amplifier tubes, nicknamed " pliotrons," whereby the original microphone currents were sufficiently amplified to control the saturation currents necessary for the magnetic controlling device.

There are to-day grave differences of opinion among radio engineers as to what type of high-power radio transmitter will prove the key to the future—the high-frequency alternator, the Poulsen arc, or the oscillion.   In my own opinion, the long-distance transmission art will shortly depart from true radiation

methods; and the a. c. generator, of comparatively *low* frequency, will be widely used for such subterranean, or submarine transmission, leaving for ship communication only the survival of

Fig. 15.
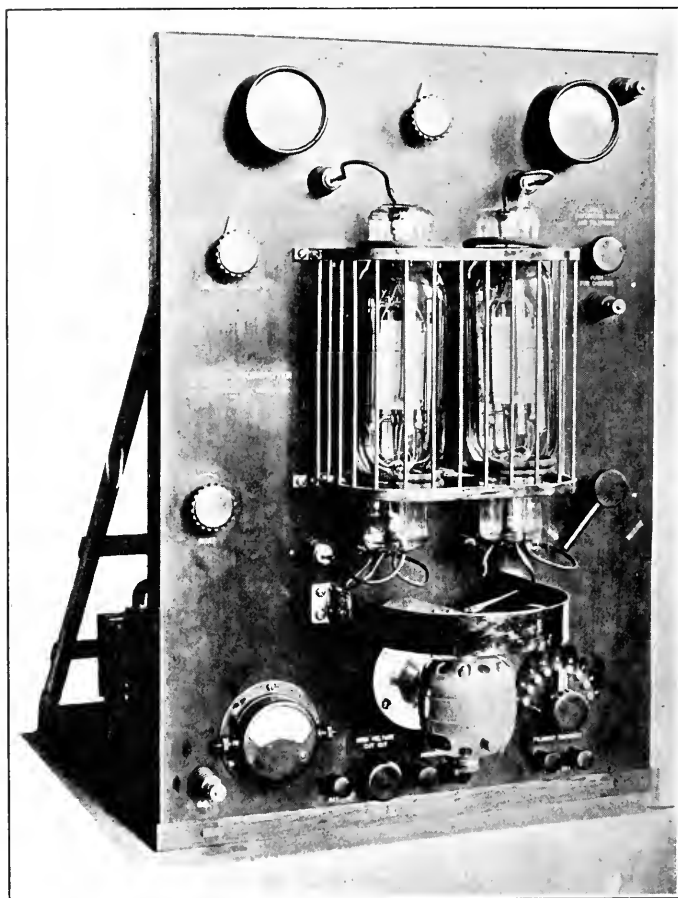
radio transmission, as it is known to-day. Such being the case, we will then have little use for *radio* transmitters of more than 20 to 50 kilowatts. For such transmitters I foresee the early use of a few large oscillion tubes, of say 5 kw. capacity each. Already we are making tubes capable of handling one and two kilowatts, using tungsten filaments and grids, and large anode

plates of tungsten or molybdenum. The efficiency with which several such tubes can operate in parallel, the ease with which an amplified voice current, acting upon their grids in parallel, can control their combined output make such a system almost ideal as a radio telephone transmitter. A typical oscillion transmitter utilizing two half-kilowatt tubes is illustrated in Fig. 15. The schematic circuit diagram for such a transmitter is shown in Fig. 16.

In the construction of these large tubes a thousand details must be scrupulously observed—in addition to the calculated physical

FIG. 16.
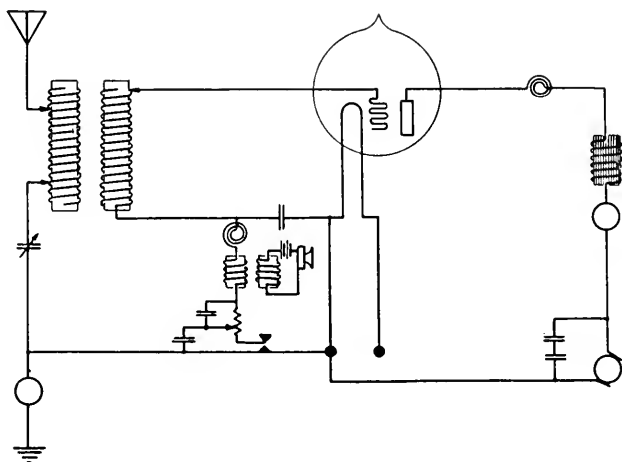
dimensions of the elements, the choice of materials, the method of seal, the preliminary treatment of the metals, their welding, the screening of the glass from bombardment, the various steps in the process of exhaustion—on careful observance of all these alone depends success in the manufacture of a high-power tube. A reasonably long life, of 500 to 1000 hours, is afforded by the tungsten filament, pure or alloyed with thorium; but this is by no means an ideal source of electrons. As such, tungsten, while preferable, is highly inefficient. By coating fine platinum ribbon with oxides of calicum, strontium, etc., or of the rare earths, similar to those in the Nernst glower, far higher emission efficiency is had, at lower temperatures, with resultant increase in life. But such oxide-coated filaments are fragile and very fre-

quently damaged during exhaust.   Moreover, many types of
coating lose their power of electron emission after a time.   This
method seems at best an imperfect makeshift.   What the audion
art awaits is a ribbon filament of some new, well-conducting
alloy, wire drawn or rolled, of non-crystalline structure, emitting
floods of electrons at a heat even lower than visibility.   Reward
awaits the metallurgist who first produces such a filament.   For
to-day the audion is being produced in quantities which in pre-war
days would have been considered fantastic exaggeration.   During
the last months of the war the world production of such bulbs
had attained the incredible rate of 1,000,000 per annum.   And
now the demand in America alone, chiefly from radio amateurs
and experimenters, is at the rate of some 5000 per month, and
constantly growing.   And most of these latter are used singly or
in two-step amplifier arrangements.   During the war, however,
thousands of amplifier and transmitter instruments, each requir-
ing 3 to 9 bulbs, were in use—in earth telegraphy, in submarine
listening, in telegraphy by ultra-violet or infra-red rays, in gun-
spotting, airplane detection, etc., in addition to those required for
ordinary radio telegraphy and telephony.

The necessary conditions for an audion to function as a gen-
erator of alternating currents have been the subject of exhaustive
study by many investigators, notably by Hazeltine, Ballantine,
and Mills in this country; Vallauri and Eccles abroad.   There
are to-day countless circuit arrangements whereby the audion
may be caused to generate such currents; but in all of the prac-
tically useful ones, where considerable power is required, the
inductive linking of the grid and plate circuits, analogous to that
first used in 1912, is in one form or another employed.   One of
the simplest forms of such circuit is shown in Fig. 17.   If there is
no time lag in the electronic stream behind the pulsations of grid
voltage, as is the case in a highly exhausted tube (up to fre-
quencies of ten million per second), then the above arrangement
becomes an alternating current source whose frequency depends
upon the natural frequency in the LC circuit.   The period of this
oscillation is very nearly $2\pi\sqrt{LC}$ if the resistance, r, of the ex-
ternal plate circuit is small, the resistance, or reactance, p, of the
plate-filament gap is great, and provided the mutual induction, m,
between the inductances in the grid-filament and plate-filament
circuits is just sufficient to maintain the oscillations.

If, then, $m > \frac{-1}{k}\left(\frac{L}{p} + r.c\right)$ this oscillating condition is realized; and K in this formula can be defined as the "amplification factor."

One of the latest developments in the oscillion transmitter is the application of alternating current for the plate voltage supply. Sixty cycle current is taken from a lamp socket, stepped up to 500 or 10,000 volts (according to the size of the transmitter)— the two halves of the cycle rectified through two-electrode vacuum valves, this rectified current stored in a suitable condenser, smoothed out by an appropriate "filter" circuit, and finally delivered as high-voltage direct current to the plate-filament circuit of three-electrode oscillator tubes. The filaments of both recti-

FIG. 17.
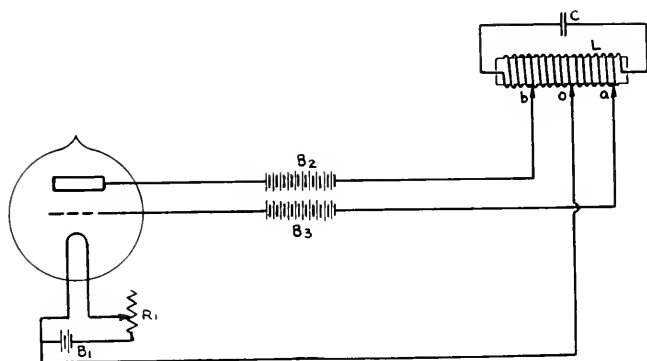
tiers and oscillators are lighted from the low-voltage windings on the one transformer. Such an arrangement does away with the motor generator converter, and even with 60 cycle supply gives surprisingly clear voice transmission. A small set of this type employing two rectifier and four small oscillating audions in multiple is shown in Fig. 18. With this small unit, consuming 50 watts and putting three-quarters of an ampere in an average antenna, one has recently telephoned fifty miles.

The developments by the engineering staff of the Western Electric Company of the audion amplifier as a telephone repeater, since my first demonstration to them of its possibilities in that field, are beyond all praise. The zeal and rare understanding of the elements of the problem with which this staff of trained men developed the amplifier and applied it to the long-sought trans-

continental telephone line stand unique in the annals of brilliant achievement in electrical engineering.

The time was ripe. Had the audion amplifier been presented at a much earlier date it is unlikely it would have then met the warm welcome which twenty years of futile search for the telephone repeater had earned for it. It was the irony of inventive fate that this revolutionary telephone device was to come, not

Fig. 18.
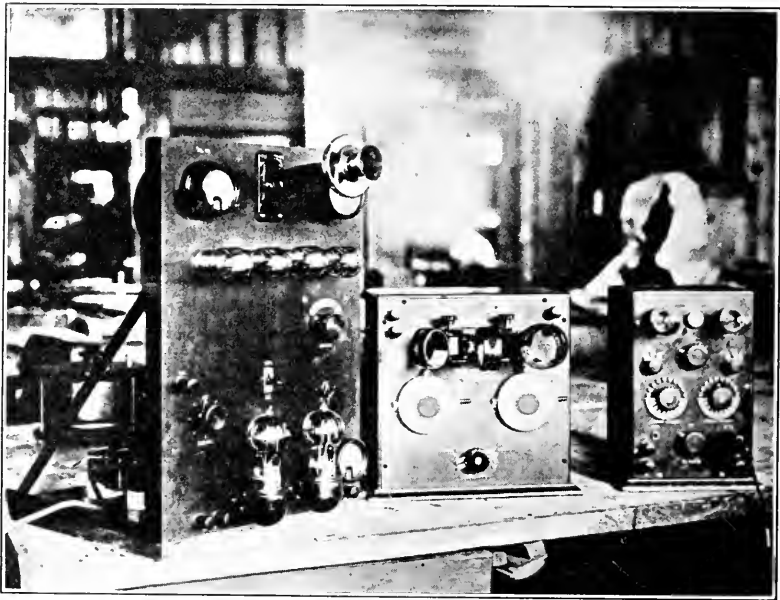
from those whose efforts had for years spun in the old rut of the receiver-microphone " siameesed " together, but from an art younger than telephony, from a device conceived for a quite different application—a wireless telegraph detector.

" From small beginnings the transcontinental line has been evolved. One element after another came. First the telephone receiver of Bell; then the Berliner—Edison microphone; then adequate line construction; the Pupin coil to prevent voice distortion—and finally the one missing link, the Audion Amplifier. Try to imagine one of the electronic carriers of the voice currents in this amplifier, and contrast it with a carbon granule of

a microphone transmitter of the early telephone relays. Compare a soap bubble with a load of coal, and you will have some relative idea of the distinction between the delicacy and elegance of the audion and that of the old microphonic relay." A more revolutionary step was never taken in the history of electrical engineering.

A repeater suitable for our present wire telephone system should supply energy amplification sufficient to restore the attenuation produced by twenty miles of standard cable. This actually means that the repeater must be capable of delivering 256 times as much energy as it receives; that is, possess a telephone efficiency of some 26,000 per cent., and this without appreciable distortion of the most intricate of voice current waves, involving all frequencies from 100 to 3000 per second. Any repeater or amplifier which produces distortion of the speech currents is to that extent unfitted for use in tandem operation, because the distortion is cumulative in the successive repeaters; and mechanical amplifiers generally, and even the best of that type, produce distortion.

A large amount of unnecessary secretiveness or mystery was for some time thrown around the type of telephone repeater which made possible transcontinental telephony.

A well-known telephone engineer has recently stated that the audion amplifiers used by the American Telephone and Telegraph Company are practically distortionless, and are commercially used in tandem operation in regular installations, and were so used in the first transcontinental line, which would have been impossible without the use of the tandem arrangement. By actual trial over cable circuits approximately one thousand miles in length it has been found that as many as thirty of these audion amplifiers can be connected in tandem and produce excellent speech at the receiving end of the line. This engineer is authority for the statement that computation shows the attentuation of a cable circuit of this length to be so enormous that if all the power received on the earth from the sun could be applied in the form of telephone waves to one end of the line, without destruction of the apparatus, the energy received at the other end would be insufficient to produce audible speech without the use of amplifiers; whereas with 30 amplifiers used in tandem the relatively minute energy of ordinary telephone speech currents at the transmitting

end produced speech in the receiver at the opposite end which was both loud and clear, the amplification due to such a tandem arrangement of tubes being of the order of 10^{50}.

The audion which has been evolved to meet these requirements, most rigorous of all its numerous applications, differs in many details from the detector or the oscillating audion. The presence here of gas ionization sufficient to cause appreciable dis-

FIG. 19.
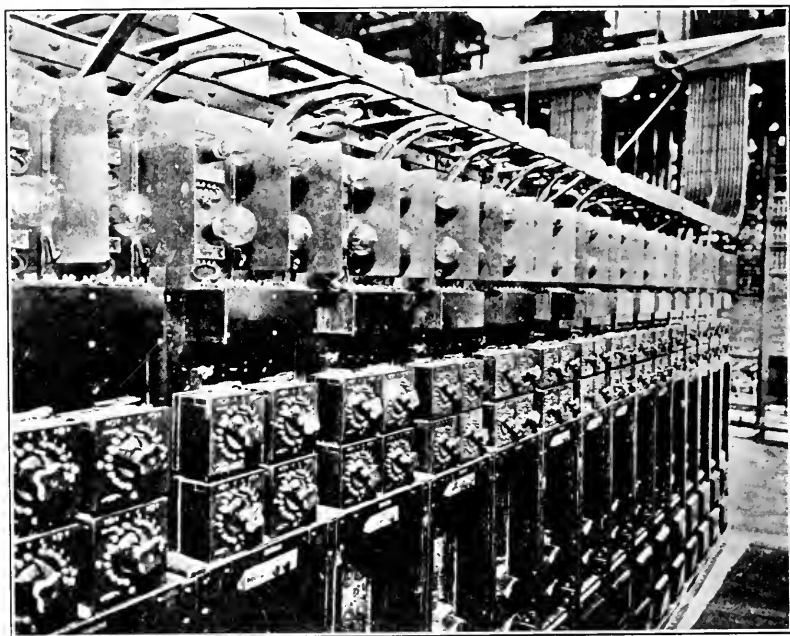
tortion cannot be tolerated, neither must the grid be permitted to be positive at any phase of the cycle of impressed voltage. A hundred other minor requirements, small yet difficult of realization, have been patiently achieved by our telephone engineers, who now state that "the amount by which it (the audion amplifier) fails to meet all the requirements for a perfect repeater is so small as to be negligible except under the most rigorous conditions."

The illustration (Fig. 19) conveys a more vivid idea than any description of the thorough completeness with which the

American Telegraph and Telephone engineers have applied the audion repeater to the commercial long-distance telephone service. It illustrates a typical group of repeater racks, each rack carrying two complete repeaters. This view was taken at one of the main repeater stations on the Boston-Washington underground cable line, located at Princeton, N. J.

FIG. 20.
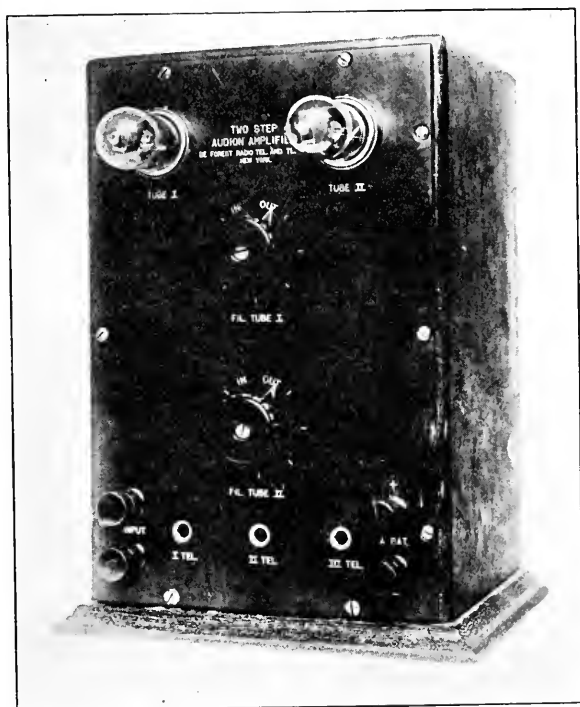
Two-stage audion amplifier.

Popular attention has been attracted to the success of the recently announced application to line wires of wireless methods of transmission, reception and tuning, whereby multiplex telegraphy and telephony have been made possible over wires already loaded down with their ordinary communication. The original ideas of such multiplex telephony date back to the early nineties, when John Stone Stone, Hutin and Leblanc disclosed methods all involving the same principle, that several alternating currents of

superaudio-frequency, each from a separate source, could be directed over the same wire or pair of wires, each be modulated or controlled by its own microphone, or Morse key, and at the receiving station each frequency taken off by its own properly tuned circuit, and there retransformed into its own original telephone or telegraph current. But none of these early investigators utilized at that time the all-necessary integrating detector which

FIG. 21.
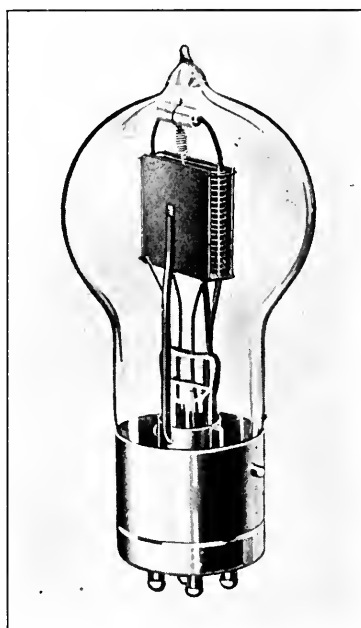
50-Watt amplifier.

was alone capable of retransforming the modulated high-frequency wave-trains back into their original audio-frequency currents. Here again the wire telephone requirements had to await the advent of a radio-detector.

General (then Captain) George O. Squier in 1910 carried out certain experiments which are destined to become classic as the new art of wired-wireless attains the important commercial proportions to which it is unquestionably destined. He, for the first time, used a constant, reliable source of undamped electric

currents of high frequency for the transmitter, and an audion detector between each tuned receiving circuit and its telephone receiver.　By this combination multiplex telephony became at once a realized fact.

But so long as a high-frequency alternator was required at each transmitter station the wired-wireless idea could not become commercialized.　Its first cost, the size and weight of it with its motor, its delicacy of speed regulation, its limitation to relatively low frequencies, all made this impossible.　So again an important development was compelled to await the advent of the oscillating audion.

Supplied from a common filament-lighting battery, a common " B " battery, or d. c. generator, any desired number of tiny alternating current generators, each driving its own easily tuned circuit, can now be assembled in a small central station.　The grid of each oscillator is voice-controlled from its local telephone circuit, and as many high-frequency " carrier " wave-trains superimposed upon a single trunk line pair, as it may be feasible to use without interferences between the modulated frequencies of the several conversations.

At present carrier frequencies ranging from 5000 to 25,000 have been used commercially over a single pair of telephone wires, between Baltimore and Pittsburgh.　A zone of frequencies of 2500 is allotted to each conversation, which permits of eight simultaneous telephone conversations over the line, in addition to the usual " physical circuit " conversations.　The constant frequency generated by each individual oscillion lies in the middle of each allotted zone of wave-frequencies, but the modulation of this " carrier wave " by the voice currents results in a wide band of frequencies (analogous to a spectrum band) on each side of the particular carrier-wave frequency.　This means that at the receiving station it is preferable to employ, instead of a circuit attuned to the single frequency of the carrier-wave, a " band-filter," or combination of several tuning elements (inductance and capacity).　This band-filter, then, is equally receptive to any wave-frequency lying within the prescribed limits, say 1,250 cycles on each side of the carrier-frequency, but offers very high impedence to all frequencies above or below the limits of the band-frequencies.　By eight such band-filter receiving circuits the eight conversations are segregated, each delivered to its own

proper audion detector and sent out on its own local telephone line.

But it is by no means necessary to limit wired-wireless to the use of such low frequencies as we have been considering. Certain tests were recently carried out in Canada which proved conclusively that frequencies as high as 500,000 per second can be used over telephone lines, including several miles of cable, without harmful attenuation. This demonstration widens very

FIG. 22.
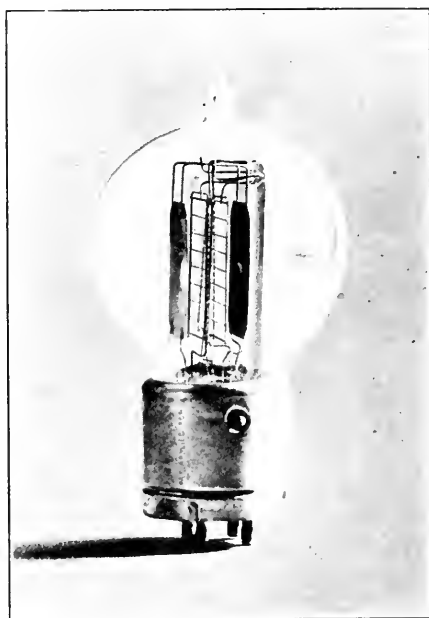
Western electric audion amplifier.

greatly the range of frequencies available for wired-wireless, with hope for a corresponding increase in the number of conversations, or telegraph communications, which can be placed upon a single pair of wires, or group of pairs. Moreover, with such high frequencies (say from 100,000 to 300,000 per second) the necessity for complicated band-filter receiving circuits vanishes, with obvious attendant advantages.

Wired-wireless is the youngest of the large family of methods for electrical communication of intelligence. He is indeed a

bold prophet who will to-day attempt to foretell the limits of its application. That the great saving in line costs, the vast multiplication of available channels of long distance communication which it makes possible will work profound changes in our present methods of business, cannot be questioned. Thus again it seems evident that the audion is destined to play a leading rôle in the work of knitting more closely the people of this land, and of all lands.

We have briefly recounted some of the main achievements which the three-electrode audion, or triode, has to its credit. Let us now consider some of the possibilities of its future. From its invention until 1912 it attracted an almost negligible interest in the scientific world. A year after the audion was first brought to the attention of the engineers of the American Telegraph and Telephone Company that corporation acquired exclusive license under all the audion patents for wire telephone purposes. Thereupon the research men of that organization initiated an elaborate line of investigation of the device, which about that time began to interest other scientists in America and abroad. Prior to 1914 not a dozen articles on the audion had appeared in scientific publications. To-day it is impossible to pick up a magazine directed to physics or electric communication without finding one or several papers dealing with some of what Dr. Eccles styes " the protean properties of the ubiquitous three-electrode tube."

Writing in the *Radio Review*, Dr. Eccles (who is affiliated with the British Marconi Co.) says : " The most important single instrument in modern wireless practice is the three-electrode thermionic vacuum valve, for it enters into every main division of the subject—it plays a dominant part in the generation of oscillations, the detections of signals, and in the amplification of feeble voltages and currents. Its arrival and devolpment have, besides, helped greatly towards the success of apparatus and methods that might otherwise have remained almost failures."

Dr. Eccles has outlined the present status and forecast of the future of the audion so clearly that I am constrained to quote further his words, as those of an unbiased observer : " During the war, hints reached the civilian that a revolution was taking place in wireless telegraphy, the principal agent in which was reported to be an instrument called a ' valve,' a ' lamp,' or a ' tube.' This instrument seemed to have arisen suddenly into a predomi-

nant position among all the apparatus of the wireless experi-
menter and operator, and appeared to be of use in every corner
of his outfit.   The complete name of the instrument is the three-
electrode thermionic vacuum tube.   It must be emphasized that
it is the three-electrode valve, and not the valve with two elec-
trodes, that has been responsible for the overthrowing of the old

FIG. 23.
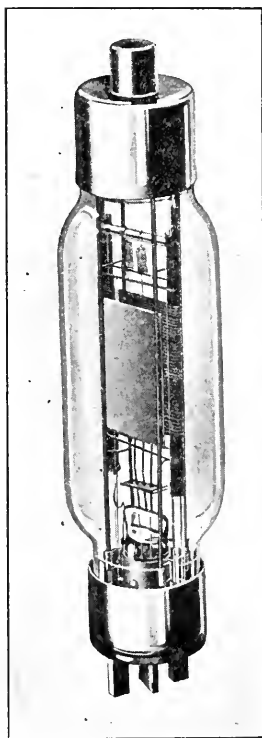
1 Kw oscillion.

methods and apparatus.   That it has been a veritable revolution
can be seen by comparing the common practice in wireless teleg-
raphy of 1914 with that of 1919.   In 1914 practically all the
most powerful transmitting stations in the world generated
waves by sparks and signals were receivel at nearly all sta-
tions by means of crystal or magnetic detectors.   The spark
method of generating waves involved the use of very large an-

tennæ for spanning great distances; and at the receiving stations
which wished to listen to stations more than even 100 miles away
very large aerial structures were customary.   But if we look at
the state of affairs to-day we find most of the high-power sta-
tions for long-distance transmission are 'continuous wave'
stations; that is, they produce uniform uninterrupted waves in-
stead of a series of short gushes made by sparks; while at the
receiving end new modes of detecting these continuous waves
appropriate to, and taking advantage of, their uniformity in
character have been introduced.   This is where the three-elec-
trode tube, in various adaptations, enters the arena.   Taken to-
gether, the improvements at both ends of the span have made
possible the use of smaller antennæ at transmitting stations, and
have almost removed the necessity for any antenna at all at
receiving stations.   For example, under reasonable weather con-
ditions, it is quite easy to listen to the messages coming from
stations on the other side of the Atlantic by using a receiving
circuit of which the receptive element is a small coil of wire,
three to four feet square.   Thus, so far as receiving goes, it is
possible to intercept all the great stations on one-half of the
globe by means of apparatus contained wholly in one room, or
even in a cupboard.   In accomplishing this the magnifications in
use amount to several hundred-thousand-fold.   All this is the
work of a thing which looks like an ordinary electric-light bulb
with a few extra pieces of metal in it—the three-electrode tube."
    Years ago what physicist did not look at the simple, self-
contained, noiseless incandescent lamp, consider it as an ideal
source of electro-magnetic waves of a wide spectrum—of heat,
visible, and ultra-violet radiation, and wonder why it should not
be made to generate also waves of any length?   To-day that in-
candescent lamp, with the addition of a metal plate and wire grid,
has become such a generator.   Undamped Hertzien radiations of
a few centimetres' wave-length can be generated by audions spe-
cially designed to give minimum capacity between the three-elec-
trodes and their lead-in wires.   From these short waves, repre-
senting alternating current frequencies of some hundreds of mil-
lions, down to those of one or two per second, the electric-wave
spectrum afforded by the oscillating audion is continuous.   Con-
sider this fact in connection with the almost infinite sensitivity
of the device as a detector, and its unlimited power as a magnifier,

or amplifier, and one realizes something of the value of the three-
electrode vacuum tube to the physicist and the inventor.   To the
former, however, the keenest interest lies perhaps in the audion
itself, because there is no known piece of electrical apparatus
linked so directly with the most recent work on the structure

FIG. 24.
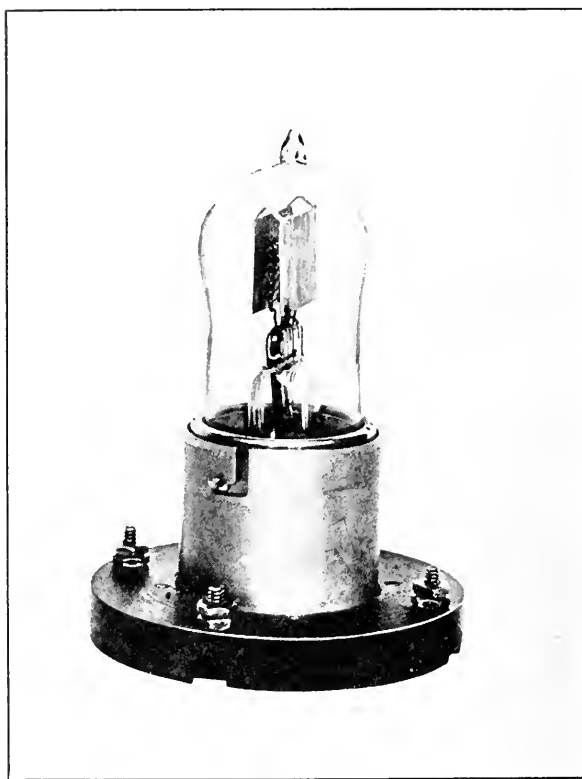
"VT-21" signal corps audion.

of matter.   A prominent British physicist has recently remarked:
" It is probable that there is no other sphere where research work
has had such a combination of immediate practical value and
intense theoretical interest."

Many an early experiment in telegraph transmission or recep-
tion by wire or wireless, long since abandoned as too limited in

range, can to-day be revived to the great benefit of man. Calculations have shown that with a littoral cable stretched for 50 miles on each side of the Atlantic, and carrying some forty amperes of 20-cycle alternating current, telegraphic communication by conduction or leakage currents should be possible, using the audion

FIG. 25.
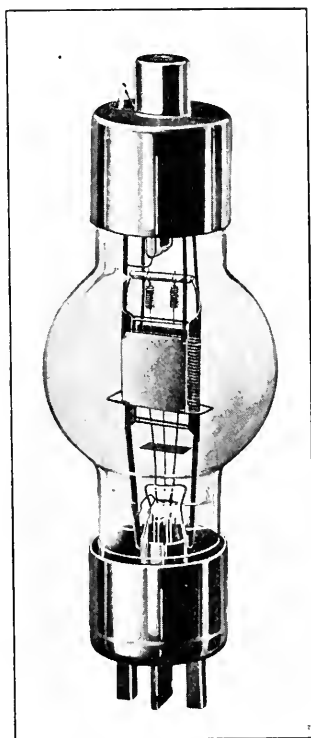
¼-Kw oscillion tube.

as detector and amplifier. I venture to prophesy that within a few years the tall towers and the atmospheric disturbances, which have for two decades been esteemed necessary evils in transoceanic wireless signalling, will be regarded with those sentiments which we now bestow upon the coherer and the spark.

But more than this. Signalling by conduction currents of relatively low frequency will soon be practiced through the earth as well as water; and we will find the antennæ of the future thrust

upside down, as into abandoned oil-well borings, and making contact with deep semi-conducting strata, at points separated by a few miles; the two inverted antennæ of such a transmitter connected by an overhead power transmission line containing the alternating current generator and signalling device; and a similar arrangement for receiving. Then our wireless messages will go through the earth's crust, or possibly by a more direct path, and not around the earth's surface, to be tangled up as at present with a bewildering snarl of static ravellings. The audion amplifier stands ready to lead us back to the simpler methods of Morse and Lindsay, meritorious methods long ago abandoned because of the lack of an electric ear of indefinitely great sensitiveness.

The future of radio signalling at sea lies with the telephone rather than the telegraph. The simplicity, the reliability with which the medium of an undamped wave-carrier, ideally suited for voice transmission, can now be had will rapidly limit the crudity and laboriousness of the Morse code signalling between ships. Yet to-day scarcely the dawn of this new epoch has been seen. Vessel owners are to-day almost as skeptical regarding the practicability and utility of the radiophone as we pioneers found them towards the wireless telegraph sixteen years ago!

In the future during fogs at sea a short-wave radio telephone will be used to prevent collisions, distances being determined (as wall as direction) by conversation, whistled signal or bell, and a calibrated stop-watch. This service will be quite independent of the long-range wireless signalling. The new radio has also a wide field of usefulness in telephoning between islands, thousands of which will never be linked by cable. Other useful fields await in sparsely peopled countries, between mines, oil wells, forest patrols, from express trains, etc. The future of aviation will be found linked with radio telephone, for a score of different purposes. Telephony by audion transmitter, receiver, and amplifier not only carries the complexes of human speech without distortion, but delivers them where human speech itself is impossible otherwise—amid the deafening motor and propellor noises of the airplane, from one to five miles above the earth.

Little imagination is required to depict new developments in radio telephone communication, all of which have lain fallow heretofore awaiting a simple lamp by which one can speak instead of read.

ON THE THEORY OF TONE REPRODUCTION, WITH A GRAPHIC METHOD FOR THE SOLUTION OF PROBLEMS.*

BY

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THE problem of ascertaining the exact extent to which it is possible by the photographic process to produce a pictorial representation of an object which will, when viewed, excite in the mind of the observer the same subjective impression as that produced by the image formed on the retina when the object itself is observed has engaged the attention of workers in the field of photography for many years. There are many phases of the subject to be considered, and a complete treatment requires a careful analysis of the various factors upon which depend the operation of our visual perception of space and spatial relations. A complete analysis, therefore, leads not only into the realm of physical science, but also into those of psychology and philosophy. It is not the purpose of this paper to present such a complete treatment, but to deal with a single phase of the subject. A careful consideration of the various factors upon which depends our visual perception of space leads to the conclusion that brightness and brightness differences (*i.e.* contrast) are by far the most important factors which are reproducible by the photographic process. The form factor (including size, shape, position, definition, etc.) to which so much importance is usually attached and which is conditioned by the performance of the image forming system, depends for its effectiveness upon the proper rendition of brightness differences. The proper reproduction of brightness and brightness differences, therefore, is of preëminent importance, and it is with this brightness factor and the possibility of its correct reproduction by the photographic process that this paper will deal.

This problem of tone reproduction, as it is commonly called,

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has frequently been regarded as requiring only the correct re-
production in the picture of the actual physical brightness of the
original, and of the actual contrast relations existing between
various areas of the object. When we consider, however, that a
given brightness or contrast may produce an entirely different
subjective impression, depending upon the state of adaptation of
the observer's eye, it is obvious that such a treatment of the subject
cannot afford a complete solution of the problem. The problem
may, in fact, be divided into two general parts, the one, which
we may term the objective phase, dealing with the reproduction
of the actual physical brightnesses and capable of being completely
solved by purely physical methods; the other, the subjective
phase, including a consideration of those factors which determine
the nature of the subjective impressions produced by the action
of given physical stimuli under various conditions, and requiring
the use of psycho-physical methods and data for its ade-
quate treatment.

Hurter and Driffield,[1] who may be considered as the founders
of the science of photographic sensitometry, treated this subject
to some extent, but confined themselves to a consideration of the
objective phase. Lord Rayleigh [2] also has treated, although
rather briefly, the objective phase of the subject. F. F. Renwick
has made valuable contributions to the solution of this problem
at various times, dealing in particular with the brightness repro-
duction possible when using the region of underexposure,[3] and
later presenting a more complete treatment of the entire subject
both from the objective and subjective viewpoints.[4]

Recently A. W. Porter and R. E. Slade [5] have published a
paper on the subject in which they take exception to some of the
conclusions reached by Hurter and Driffield, and outline the re-
lations which they consider essential for the solution of the prob-
lem. They also deal only with the objective phase, the reproduc-
tion of the actual physical factors. Following this, two short
papers of a somewhat controversial nature dealing with special
cases of the tone reproduction problems have appeared, one by

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[1] *Jour. Soc. Chem. Ind.*, May, 1890, and February, 1891.

[2] *Phil. Mag.*, vol. xxii, 1911, p. 734.

[3] *Phot. Jour.*, vol. xxxvi, 1913, p. 127.

[4] *Phot. Jour.*, vol. xl, 1916, p. 222.

[5] *Phil. Mag.*, vol. xxxviii, 1919, p. 187.

Mr. F. F. Renwick [6] and the other by Messrs. Porter and Slade.[7] Finally Mr. Renwick [8] has published a paper in which he gives in detail the method by which he obtained the results previously published (*loc. cit.*) relative to the objective phase of the subject. His conclusions are in substantial agreement with those arrived at in the following treatment of the subject although a quite different graphic construction was used.

During the past five years a large amount of work has been done in this laboratory on the theory of tone reproduction, and a satisfactory solution for the objective phase was obtained some two or three years ago. Application of this method was made to a special problem, the determination of the color coefficients of various selective photographic images, the results being published by the author in collaboration with R. B. Wilsey in the JOURNAL of THE FRANKLIN INSTITUTE, Vol. 185 (1918), p. 231. While the precise method of procedure in the paper cited (see page 253) applies only to the special problem considered, which was not fundamentally tone reproduction, use was made of the basic principle which constitutes the method for the solution of the tone reproduction problem to be presented in this paper. The publication referred to is mentioned merely as an instance of a special problem in photographic research to which the more general method may advantageously be applied. Simultaneously with the work of tone reproduction, research in the field of visual sensitometry has been in progress, which has resulted in data applicable to the solution of the subjective phase of the more general reproduction problem. The results of this work have been published as communications from this laboratory by P. G. Nutting,[9] Julian Blanchard,[10] and Prentice Reeves.[11]

While some particular details of the subjective data are still lacking, it is felt that sufficient information is now available to establish the general nature of the function necessary for the con-

[6] *Phil. Mag.,* vol. xxxviii, 1919, p. 637.

[7] *Phil. Mag.,* vol. xxxviii, 1919, p. 637.

[8] *Phil. Mag.,* vol. xxxix, 1920, p. 151.

[9] JOURNAL OF THE FRANKLIN INSTITUTE, vol. clxxxiii, 1917, p. 287; *Trans. Ill. Eng. Soc.,* vol. xi, 1916, p. 939.

[10] *Phys. Rev.,* vol. xi, 1918, p. 81.

[11] *Jour. Opt. Soc. Amer.,* i, 1917, p. 148; *Astro. Phys. Jour.,* xlvii, 1918, p. 141; *Psychol. Rev.,* vol. xxv, 1918, p. 330.

version of objective reproduction into its subjective equivalent. In the meantime further work is being carried out in order to make possible a more precise quantitative evaluation of this function.

SIMPLIFYING ASSUMPTIONS.

In order to simplify the subject, and bring it within the limits of a single paper, it will be necessary to make certain simplifying assumptions. Since the sensitivity of the photographic plate to radiation of different wave-lengths is in general radically different from that of the eye, objects in which color is present have not in general the same brightness when considered from the visual standpoint as when the evaluation is in terms of the photographic plate.

Let us, therefore, assume that all areas of the object considered are both visually and photographically non-selective (*i.e.,* colorless), and further that the optical system forming the image of the object on the negative material is likewise non-selective. Under such conditions values of visual brightness are directly proportional to photographic brightness. Thus this treatment will deal with brightness relations uncomplicated by any consideration of selectivity. Let us further assume that all photographic deposits considered are also non-selective in order that visual and photographic density values may also be considered as identical.

TERMINOLOGY AND SYMBOLS.

The problem to be treated involves so many operations, materials and inter-relations that it is of considerable importance at the outset to adopt a logical system of terminology and symbols. In order to obtain a satisfactory foundation, let us consider briefly the various steps in the complete cycle involved in obtaining a reproduction by the photographic process. An image of the object (O) must be formed on the negative material (X) by a suitable optical system. Under our first assumption it will be unnecessary to distinguish between the photographic and visual characteristics of the object. The characteristic of the object of interest is its brightness, while that of the image formed on the negative material is the illumination. The image illumination is transformed into an exposure by the action of the time factor. The exposed sensitive material is now developed, thus being transformed into a negative, N. The essential characteristic of the

negative is transmission or density. The negative is now used to form an image, either by contact or projection, on the positive material Y. The most useful specifications of this image is its illumination, for the determination of which it is necessary to know the illumination incident on the negative. The illumination of the image is transformed into an exposure by the factor of time. The exposed positive material is now transformed by development into a positive, P, of which it is necessary to know the density values. The positive becomes an objective reproduction, which in order to avoid confusion in the system of terminology we will refer to as the "material" reproduction, when it is illuminated, and is characterized by its brightness values. The character of the subjective reproduction resulting when this objective reproduction is viewed by an observer is dependent upon its brightness values and the retinal adaptation of the observer. Finally the evaluation of the subjective reproduction relative to the subjective impression due to the object, which we shall for sake of brevity call the "subjective object," involves a consideration of the brightness values of the object and the retinal adaptation existing when viewing that object.

The "things" involved therefore are:

	Symbol
1. Object	O
2. Negative sensitive material	X
3. Negative	N
4. Positive sensitive material	Y
5. Positive	P
6. Material Reproduction	MR
7. Subjective Reproduction	SR
8. Subjective Object	SO

The first six of these are objective or physical in nature, while the last two are subjective or perceptual. An evaluation of O in terms of MR gives a function which defines the extent to which actual objective reproduction of brightness is obtained under the limiting conditions assumed while an evaluation of SO in terms of SR gives the function required to determine the reproduction of the subjective impression.

The symbols as indicated for these "things" will be used as subscript letters attached to the symbol for the various physical factors applying to them.

The physical factors are:

	Symbol
Radiant Flux	F
Illumination	I
Brightness	B
Reflection Coefficient	R
Transmission Coefficient	T
Exposure	E
Time	t
Density	D

Some of the fundamental relations existing between these factors are:

$$E = I \cdot t.$$
$$D = \log \frac{1}{T}$$
$$B = I \cdot R \text{ or } I \cdot T.$$

If, for a given absorbing layer,

F = Incident Flux, and

F' = Transmitted Flux (or Reflected Flux),

$$T = \frac{F'}{F}$$
$$R = \frac{F'}{F}$$

As an example of the use of subscript letters according to this system:

E_x = Exposures given to negative material.

E_y = Exposure given to positive material.

D_n = Density of negative.

T_n = Transmission coefficient of negative.

B_o = Brightness of object.

I_n = Illumination incident on the negative (during printing).

Other particular values of the physical factors are indicated in a similar manner.

In Table 1 is given a schematic outline showing the various steps in the computation of the final result of a given tone reproduction problem. It will be noted that the process is divided into ten distinct steps represented by the Roman numerals I to X. The necessary factors required at each step are designated by the corresponding Arabic numerals. In the parenthesis designated by the letters A, B, C, etc., are statements either verbal or sym-

bolic of the transformation factors which convert the factor of one step into that of the next succeeding step. As the starting point, I, it will be noted that the " subjective object " is taken, by which is meant the subjective impression of brightness and brightness contrast excited in the mind of the observer. This impression, it is obvious, is the thing which it is desirable to reproduce rather than the actual physical brightness values which are measured by the usual physical methods. In practice, however, it is more convenient to take as the actual starting point of the operation the measured brightness values, B_o, of the object and to evaluate the subjective relation between B_o (II) and B_{so} (I) relative to that between B_{mr} (IX) and B_{sr} (X) after having obtained the necessary values of B_{mr}.

<div align="center">TABLE I.</div>

I. The Subjective Object (SO).
   1. Subjective brightness of object (B_{so}).
      A. (Adaptation level of observer when viewing object, A_o
        $B_{so} = f$ (A_o).)
II. Object (O).
   2. Brightness (B_o).
      B. (The constant of the image forming system, K_x.)
III. Image on the X (negative) material.
   3. Illumination (I_x) $= B_o$. K_x.
      C. (Exposure time, t_x.)
IV. Exposure on the X (negative) material.
   4. Exposure $E_x = (I_x$. $t_x)$.
      D. (Development, fixing, washing, drying, intensification, reduction, etc. Specified by $D_n = f(E_x)$.)
V. Negative (N).
   5. Density, D_n, or Transmission, T_n.
      E. (Illumination, I_n.)
VI. Image on the Y (positive) material.
   6. Illumination, $I_y = (T_n$. $I_n)$.
      F. (Exposure (printing) time, t_y).
VII. Exposure on the Y (positive) material.
   7. Exposure $E_y = (I_y$. $t_y)$.
      G. (Development, washing, fixing, toning, etc. Specified by
        $D_p = f(E_y)$.)
VIII. Positive (P).
   8. Reflecting Power, R_p.
      H. (Incident Illumination, I_p.)
IX. The Material Reproduction (MR).
   9. Brightness (B_{mr}) $= (R_p$. $I_p)$.
      I. (Adaptation level of observer, A_{mr}. $B_{sr} = f(A_r)$.)

THE NECESSARY DATA.

Before considering the method of obtaining the tone repro-duction solution, it will be well to consider briefly the individual groups of data which must be utilized. These may be summarized as follows:

1. Relative to the Observer:
   A_o Adaptation level of eye when observing the object.
2. Relative to the Object:
   B_o Brightness values for various areas of the object.
3. Relative to Image Forming System:
   K_x Factor converting B_o to I_x.
4. Relative to Negative Material:
   $D = f(E)$ The H and D curve of the material.
5. Relative to Printing System:
   I_n Illumination incident on negative during printing.
6. Relative to Positive Material:
   $D = f(E)$ The H and D curve of the material.
7. Relative to Material (Objective) Reproduction:
   I_{mr} Illumination on the print during observation.
8. Relative to the Observer:
   A_{mr} Adaptation level of the eye while observing the reproduction.

As a typical example of the data mentioned under No. 4, the curve in Fig. 1 is given. This is for a typical negative material of good quality, the ordinates being values of density (D) and the abscissæ the corresponding exposure plotted on a suitable logarithmic scale. In Fig. 2 is given a typical example of the same function ($D = f(E)$) for a positive material, in this case a photographic developing-out paper. In case the positive is made on a transparent base, the curve will be of the same general type, but resembling more closely with respect to absolute values the curve shown in Fig. 1. In order to determine the relation between the objective and subjective reproduction, it is necessary in addi-tion to the factors mentioned previously to use the sensibility function of the eye. In Fig. 3 are plotted the curves showing the retinal sensibility to brightness and brightness differences as a function of adaptation level. These curves are obtained from

data by Nutting and Blanchard, and constitute the most reliable information available relative to the subject.

Curve A is plotted with values of sensation (S) as ordinates against the logarithm of the field brightness (B). Curve B is the first derivative of A, and is plotted with values of $\frac{B}{\triangle B}$ as ordinates. This curve gives the contrast sensibility of the eye for the

FIG. 1.
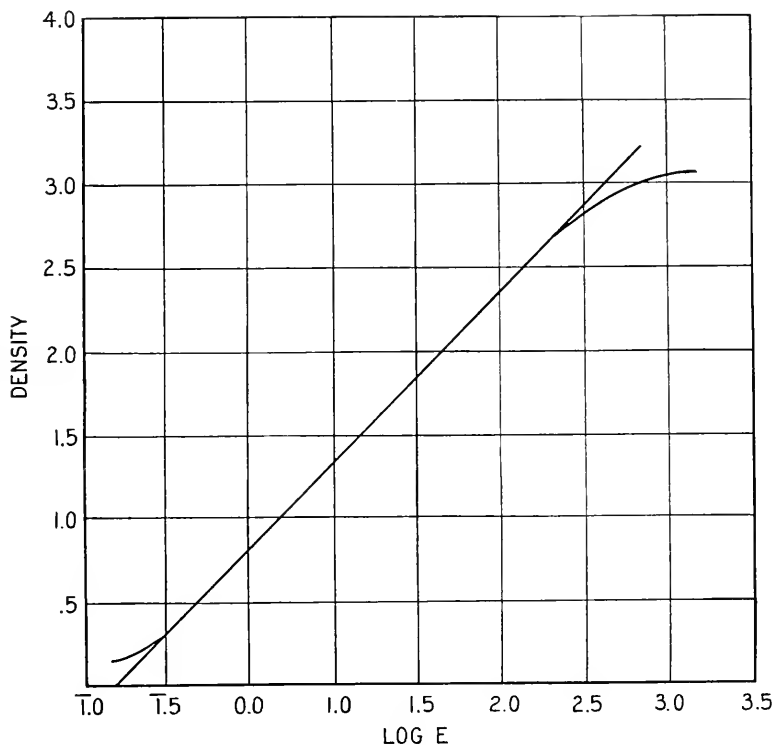
Characteristic curve of negative material.

various values of B (plotted on a log scale). The relation between curves A and B, that the sensibility curve is the first derivative of the sensation (response), is a general one,[12] this being true for the corresponding curves of any physical instrument which indicates by some response (scale reading) the magnitude of the applied stimulus.

The data contained in the curves of the three figures (1, 2, and

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[12] Nutting, P. G.: *Bull. Bur. Stds.*, vol. v, 1908, p. 266.

3) with the other values mentioned in the tabulation (p. 46) constitute the material from which a complete solution of the tone reproduction problem can be constructed. Having then made certain simplifying assumptions, established a satisfactory system of terminology and symbols, and considered briefly, in a general

FIG. 2.
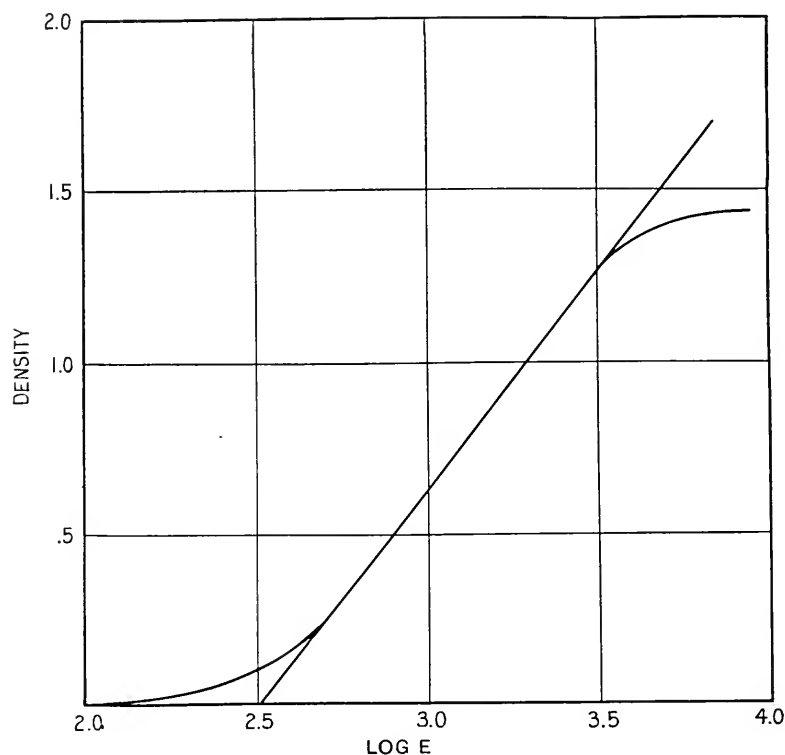
Characteristic curve of positive material.

way, the problem and the necessary factors involved, let us proceed to the development of the graphic and analytical solutions.

A GRAPHIC SOLUTION.

The graphic solution is presented in Fig. 4, the necessary curves being plotted in the four quadrants designated for reference as *I, II, III*, and *II'*. For convenience in plotting a double scale along the *OX'* axis, a separation between the upper and

lower quadrants is made, the two points designated by O being, in fact, identical.

Along the line OX is established a suitable logarithmic scale upon which may be plotted the logarithms of the brightness values for the various areas of the object. Let the points a_0, b_0 and c_0 represent three typical object-brightness (B_0) values, a being the lowest and c the highest which exist in the object considered. After having located on this scale (log B_0) the various points

Fig. 3.

Contrast sensitivity curves of the eye.
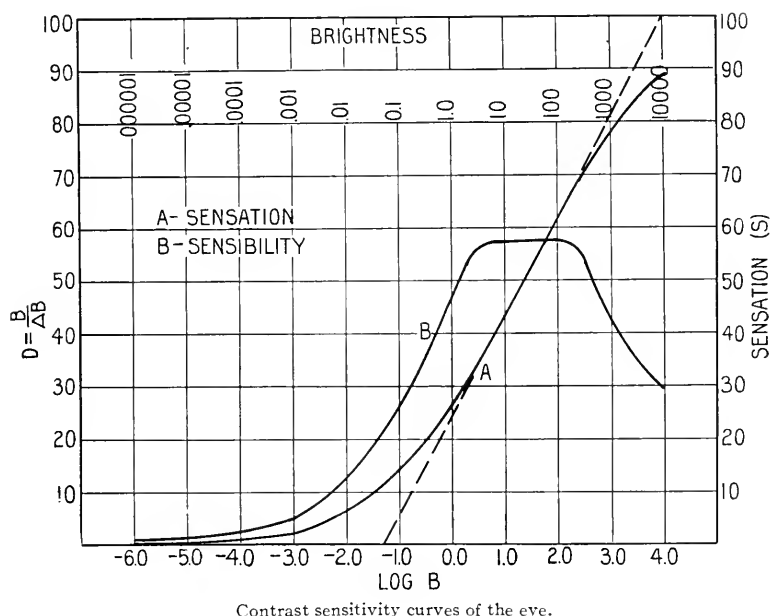
representing the brightness values of the object which it is desired to reproduce, the curve A is plotted directly under the log B_0 scale, and properly placed in the horizontal direction relative to the points on the log B_0 scale. This curve A is the characteristic H and D curve of the sensitive material on which the negative is made. It must be determined by sensitometric methods such that it is a true representation of the characteristic of the negative material when used under the conditions existing in the making of the negative, such conditions including those factors operative in transforming the latent into a real image as well as

the necessary physical condition relative to quality and intensity of the exposing radiation. This characteristic is therefore the curve of effective printing densities as defined and determined in the paper previously mentioned (Jones and Wilsey). Curve A is

FIG. 4.

Graphic solution for the objective phase of tone reproduction.

plotted with values of log exposure as abscissæ and densities as ordinates, the log E_x scale being laid off on the line Y', $Y'X$, and the density scale on the line $Y''X$, X.

The density values for the negative include the density of both fog and supporting material as well as of the silver deposit due to the exposure, thus being values of total density. Since the as-

sumption has been made that the deposits are non-selective, it follows that the color-coefficient is unity. It was assumed that the density values are determined under such conditions of illumination (diffuse or specular) that they are true values for the printing process used, contact or projection as the case may be. The unit interval on the log E_x scale must be equal to the unit used in establishing the log B_0 and equal also to the unit interval of all log-scales used throughout the solution. The adjustment of the scale of log E_x along the line Y', $Y'X$, depends upon the choice of the negative density value (D_n) by which it is desired to render a given object brightness. For instance, if it be desired to render point a_0, the lowest brightness in the object by a negative density of .20, the scale of log E_x is so adjusted that when curve A is plotted the perpendicular dropped from point a_0 will cut the curve at a density value of .20.

The relation between the log B_0 and the log E_x scale will now determine the exposure that must be given to the sensitive material on which the negative is to be made in order to obtain the rendition of the chosen brightness value by the desired negative density. In order to compute the exposure time, t_x, however, certain constants of the image forming system used in imaging the object on the sensitive material must be known.

Let the constant K_x be defined as that value by which a given value of object brightness, B_0 must be multiplied in order to obtain the value of the illumination, I_x, incident on the negative material at the point where that particular area of object is imaged. K_x is, therefore, the value which satisfies the equation.

$$B_0 \cdot K_x = I_x$$

$$\frac{E_x}{I_x} = t_x$$

$$\therefore \quad t_x = \frac{E_x}{B_0 \cdot K_x} \text{ , or}$$

$$\log t_x = \log E_x - (\log B_0 + \log K_x)$$

In order to compute t_x (K_x being known), it is only necessary to read the values of log B_0 and log E_x at the points where any line parallel to OY cuts the two scales and substitute in the equation.

The value of the constant K_x depends on several factors such

as diameter of stop, object and image distances, spectral transmission of the lens material, etc. The evaluation of K_x in terms of these various factors is somewhat complex, and will not be considered at this time.

Now it is convenient to regard the negative produced by the development of the exposed sensitive material (X) as a means of impressing a series of various exposures upon the sensitive material (Y) upon which the positive or print is to be made. The D_n scale must, therefore, be transformed into an inverse scale giving the relative values of the various illuminations which the negative will allow to act upon the material Y during the printing operation. Let I_n be the illumination incident upon the negative during printing, and I_y the illumination transmitted by the negative and therefore incident upon the positive material Y. Let T_n be the transmission coefficient of the negative. T is related to D (Density) by the equation:

$$D = \log \frac{1}{T}$$

and T is defined by the equation,

$$T = \frac{I_1}{I_0}$$

where $I_0 =$ the incident illumination; $I_1 =$ the transmitted illumination.

Hence:
$$I_y = I_n \cdot T_n$$
$$\log I_y = \log I_n + \log T_n$$
$$= \log I_n - D_n$$

Since I_n is a constant, differentiation gives $d \log I_y = -d\, D_n$. Hence, any interval on the $\log I_y$ scale is numerically equal to the corresponding interval on the D_n scale but of opposite sign. Now along the line OY'' establish a log scale on which the value of I_y computed from the known values of D_n and some suitably chosen value of I_n may be plotted.

In quadrant III, plot curve B, the characteristic curve of the positive material (Y). This must be determined also under conditions which give the true characteristics of the material as used in making the print from the negative. The abscissæ values of this curve are the densities D'_p while the ordinates are the corresponding exposure values plotted on the scale of $\log E_y$ established in a suitable position on the line X', $X'Y'$.

The scale of log E_y must be so adjusted along the line X', $X'Y'$ that the curve B when plotted will occupy the proper position in the vertical direction relative to the position of curve A. The proper position of curve B is determined by deciding by what value of D'_p it is desired to render some chosen value of D_n. For instance, let it be required to render the highest brightness, c_0, of the object by a just perceptible density on the positive. Assuming that the resulting print is to be viewed with an illumination such that the eye is operating in the region of maximum sensitiveness of brightness difference, a deposit differing in brightness by 2 per cent. from the background will be just perceptible. This is equivalent to a transmission or reflection coefficient of 98 per cent., which corresponds to a density of approximately .008. In order to fulfill the requirement, it will be necessary to adjust the scale of log E_y so that when the curve B is plotted a horizontal line drawn through the point where $D'_p =$ .008 will cut curve A at c_n, which is also the point where a perpendicular dropped from c_0 cuts curve A. The relation between the values of log E_y and log I_y at the points where any line parallel to $X'O$ cuts the two scales determines the exposure necessary to obtain the desired result.   Thus:

$$\frac{E_y}{I_y} = t_y$$

or

$$\log t_y = \log E_y - \log I_y.$$

Substituting in this equation the values of I_y and E_y the value of t_y, the exposure time necessary may be determined.

It will be remembered that in order to establish the scale of log I_y a value of I_n was assumed. Since an arbitrary choice of this value, without previous knowledge of the speed of the positive material Y may lead to inconvenient or absurd values of t_y, it may be more logical to omit the establishment of the I_y scale and take the relative value of log E_y and D_n at the points where any horizontal line cuts the respective scales as a means of determining the exposure necessary in making the positive.

Thus:

$$\log t_y = \log E_y - \log I_y,$$

but,

$$\log I_y = \log I_n - D_n,$$

therefore,

$$\log t_y = \log E_y - \log I_n + D_n$$

The corresponding values of log E_y and D_n having been determined, two variables, I_n and t_y, remain, and by choosing a convenient value of t_y the value of I_n (the illumination incident on the negative during printing) necessary to satisfy the equation may be found.

Now let the points a_p, b_p, and c_p be located on curve B at the points where horizontal lines passing through the points a_n, b_n, and c_n intersect curve B, the points a_n, b_n, and c_n having been located at the intersections of curve A with perpendiculars dropped from points a_o, b_o, and c_o.

Along the line OX' lay off a log scale opposite in direction to the scale of log B_o. The scale OX' is that from which the reflection coefficient (R_p) (or transmission coefficient T_p) of the various areas of the positive are determined. The position of this scale along the line OX' is determined by consideration of the values on the D'_p scale and the reflection or transmission coefficient of an area of the positive which has received no exposure. Let R_b (or T_b) be the reflection coefficient of such an area.

The values of D'_p are derived from the measurement of the reflection or transmission coefficient of the various areas of the positive relative to the reflection or transmission coefficients of an unexposed area of the positive material which has received, of course, the same development treatment as the other areas of the positive. These values, therefore, are of relative reflection (or transmission) coefficients. This method of measuring and specifying positive densities is preferable (especially in the case of positives to be viewed by reflected light) from the standpoint of practice, and is the usual procedure in the sensitometry of positive materials. But in order to find the brightness of the various areas of the positive, when observed under a given condition of illumination, it is necessary to know their absolute reflection coefficients. It is necessary, therefore, in order that the values of R_p (or T_p) read from the log R_p scale may be in absolute terms and suitable for the computation of resulting brightness values (B_{mr}) to lay off the values of this scale (log R_p) so as to include the factor R_b (or T_b). The relation between the relative and absolute reflection (or transmission) coefficients is given by

$$R'_p \cdot R_b = R_p$$

or

$$\log R'_p + \log R_b = \log R_p.$$

Where R'_p is defined by the equation

$$\log R'_p = -D'_p.$$
$$\therefore \log R'_p = + \log R_b - D'_p$$

The scale on OX' must therefore be so constructed that at corresponding points on the $\log R_p$ and $\log D'_p$ scales the relation between the values of R_p and D'_p shall be as indicated in this equation.

This equation for the case of a positive material on a transparent base and intended to be observed by transmitted light becomes

$$\log T_p = + \log T_b - D'_p$$

In such cases it is sometimes more convenient to measure the values of D'_p in absolute terms, that is, they already include density of the unexposed area. The term T_b therefore becomes unity, making $\log T_b$ zero and the relation is expressed simply as,

$$\log T_p = -D'_p$$

Now the points a'_p, b'_p and c'_p are located on the $\log R_p$ scale at the intersections of the perpendiculars through the points a_p, b_p, and c_p, with the line OX'.

The values read from the scale at these points (a'_p, b'_p and c'_p) are the reflection (or transmission) coefficients of the areas on the positive by which the areas of the object represented by the points a_o, b_o and c_o are rendered.

The brightness (B) of a surface in terms of its reflection coefficient (R) and the incident illumination (I) is given by the relation,

$$B = I \cdot R$$
$$\log B = \log I + \log R$$

Assuming then that the illumination on the positive during observation is I_p the brightness of any given area of the material (objective) reproduction is obtained by the relation

$$\log B_{mr} = \log R_p + \log I_p$$

The brightness of the areas a_p', b_p', and c_p' can, therefore, be computed for any assumed value of the illumination under which the positive is observed or the value of I_p can be computed for any assumed brightness for a given area. On the line OX' establish a log scale such that for corresponding points on this and the log

R_p scale (b_p' and b_{mr}, for instance) the values of log B_{mr} and log R_p will with the assumed value of I_p satisfy the equation

$$\log B_{mr} = \log R_p + \log I_p.$$

Or, if it is desired that any given area of the positive be of the same brightness as the corresponding area of the object, the value of I_p necessary can be computed by the relation.

$$\log B_o = \log B_{mr} = \log R_p + \log I_p,$$
$$\log I_p = \log B_o - \log R_p,$$

where log B_o and log R_p are the values for corresponding points of object and positive such as, for instance, b_o and b_p'. Since the relation between the reflection coefficients of the various areas of the positive may be entirely different from the relation between the brightness values of the corresponding areas of the object, it is in general possible to realize this equality of brightness condition for only one point on the positive. In practice, however, it is found that by proper adjustment of conditions it can be realized throughout a finite range, which in some cases is a considerable proportion of the entire tonal range of the object.

Now in considering the extent to which a given positive observed under given illumination reproduces the subjective impression caused by observation of the object itself, it is necessary to take into account the state of adaptation of the observer's eye not only while viewing the reproduction, but also when looking at the object. The curve which determines the relation between what we shall term the material reproduction and the subjective reproduction is, in the complete graphic solution, plotted in quadrant IV, and is referred to as the subjective relative-contrast function. In order to avoid confusion, it will be well for the present to omit consideration of this step in the problem and to complete the first solution for material reproduction, after which a more comprehensible exposition of the subjective phase will be possible.

In order to obtain the reproduction curve, it is necessary to transfer the points a_{mr}, b_{mr}, and c_{mr} to the OY axis. This can be done by simply rotating the log B_r scale about the point O until it coincides with the line OY, but since later a surve (the subjective relative contrast function) will occupy quadrant IV it will be better to make use of what may be termed a " dummy " curve (C) in II', this being simply a line making an angle of 45° with the

line OX' and passing through O. Vertical lines through the points a_{mr}, b_{mr}, and c_{mr} intersecting curve D locate the points a_d, b_d, and c_d on this curve and horizontal lines through these intersections locate by their intersection with the line OY the position of the point a_{mr}, b_{mr}, and c_{mr} on this scale. Now the intersections of the horizontal lines through a_{mr}, b_{mr}, and c_{mr} (on line OY) with the vertical lines through a_o, b_o, and c_o determine the points a_x, b_x, and c_x which, when connected as shown, established the shape and position of the reproduction curve D (in I). This affords a graphic representation of the relation between the brightness factors of the object and those of the material reproduction (the illuminated positive). Now, though the point on the log B_{mr} scale (on line OY) where log B_{mr} is equal to the value of log B_o read at the point O (on line OX) draw a line parallel to OX. In the figure this is represented by the broken line $O'M$. This line is the absolute x axis of the reproduction curve D while the line $O'Y$ is the corresponding y axis, O' being the absolute origin. The line OX can be retained as the absolute axis by displacing the point of intersection of the dummy curve C (IV) in the proper direction along the X axis (line X', O, X) by a distance equal to OO'. (In the case shown in Fig. 4 this point would be to the left of O at O''.) In practice, however, such procedure usually results in the displacement of the reproduction curve, D, in the vertical direction by an inconvenient amount and location of the new position of the absolute axis as indicated is usually more convenient. In some cases this method may result in the point O' falling outside the limits of the available coördinates, in which case its location is best indicated by a dimension line carrying a numerical indication of its position relative to the apparent axis OX.

Now a straight line drawn through O' and making an angle of $45°$ to the line $O'M$ is the curve E, of absolute reproduction, this term being used to denote an exact reproduction in the material reproduction of both the brightness and contrast of the object. For any point on the reproduction curve, D, the magnitude of the departure from an exact reproduction of brightness is given by the length of the perpendicular line limited by the two curves D and E and drawn through the point considered; while the relation of the slopes (first derivatives) of the curves at corresponding points (b_d and b_x, for instance) determine the magni-

tude of the departure from exact reproduction of the contract in
the object at the point (*b*) considered.

The fact that the curve *E* is the curve for the exact reproduc-
tion of brightness follows from the construction which is such that
for any point on this curve log B_o is equal to log B_{mr}, thus satis-
fying the necessary condition that $B_o = B_{mr}$. The fact that a given
brightness interval of the object is represented by the same bright-
ness interval on the curve *E* indicates that the contrast of the
object has been exactly reproduced. A straight line at 45° to the
axis is the necessary condition for exact contrast reproduction,
while for exact reproduction of brightness this line must pass
through a certain specified point on the log B_{mr} scale.

From the position of the curve *E* relative to *D* (the reproduc-
tion curve), it is possible to determine quantitatively the magni-
tude of the departure from the condition of exact brightness re-
production. The most convenient method of expressing the mag-
nitude of this departure is by use of the ratio of the brightness of
the object to the corresponding brightness of the reproduction,
which ratio will be designated by the symbol ΔB.

$$\Delta B = \frac{B_o}{B_{mr}} \text{, or}$$

$$\log \Delta B = \log B_o - \log B_{mr}$$

Hence, if on the log B_{mr} scale (line *OY*) the values for any
pair of corresponding points on the curves *E* and *D* (b_a and b_x, for
instance) be read, ΔB can be determined. Since for any point on
E, log B_o = log B_{mr}, the value of log B_{mr} can be substituted for log
B_o. For instance, consider the pair of corresponding points a_x
and a_a

$$\log \Delta B = \log B_o \text{ (at } a_o) - \log B_{mr} \text{ (at } a_x),$$
$$\text{and } \log B_o \text{ (at } a_o) = \log B_{mr} \text{ (at } a_a),$$
$$\therefore \log \Delta B = \log B_{mr} \text{ (at } a_a) - \log B_{mr} \text{ (at } a_x).$$

It also follows since the length of the line $a_a\ a_x$ is given by

$$a_a\ a_x = \log B_{mr} \text{ (at } a_a) - \log B_{mr} \text{ (at } a_x).$$

that log ΔB = the line $a_x\ a_a$.

Hence in order to plot the curve of brightness deviation in
terms of its logarithm, it is only necessary to use as ordinates the
lengths of the perpendiculars lying between the two curves *D* and
E. For the sake of convenience and the avoidance of confusion
due to a multiplicity of lines, this curve is not plotted in Fig. 4,

but is transferred to Fig. 5, the log B_0 scale being a duplicate of that in Fig. 4 and the ordinates the values of log ΔB. The line OX passing through the point log $\Delta B = o$ ($\Delta B = 1.0$) is the line of no deviation, hence the axis of exact brightness reproduction. In plotting the curve of log ΔB (Fig. 5) the sign of the

Fig. 5.

LOG B_0
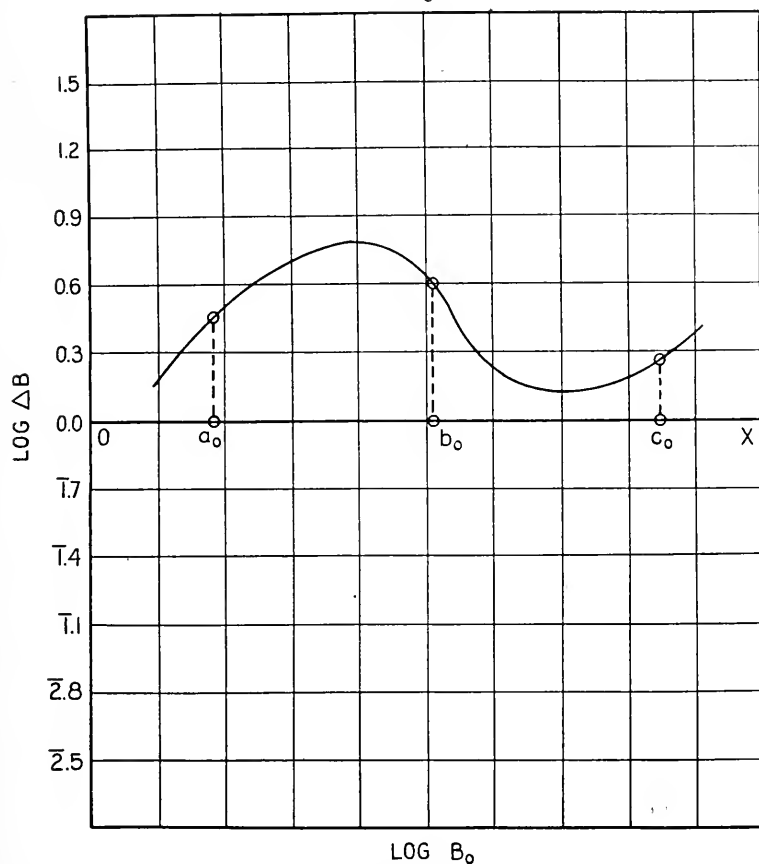
Curve of brightness deviations.

quantity log ΔB must be considered. A point lying below the curve E (Fig. 4) will be represented in Fig. 5 by a point above the line OX and *vice versa*, a value of log ΔB greater than $o.o$, indicating that ΔB is greater than unity, and hence that B_0 is greater than B_{mr}, while a value of log ΔB less than $o.o$ shows that B_0 is less than B_{mr}.

ANALYTICAL CONSIDERATIONS.

Let us now apply the method of the differential calculus to the functions plotted in Fig. 4. Such treatment is especially useful in a determination of the contrast relations existing between the various elements. If at any point the ratio of some small increment ΔY (in the direction of the Y coördinate) to the corresponding increment ΔX (in the direction of the X coördinate) be computed the value obtained is a measure of the average slope of the curve over the distance (ΔX) considered. When these increments are reduced to the infinitesimal dy and dx the ratio gives the value of the slope at a point on the curve. Hence, if the slope or gradient be designated by the symbol G, it is defined by the expression $G = \frac{dy}{dx}$. Applying this then to the curves of Fig. 4, the following expressions are obtained.

The density gradient of curve A, the characteristic of the negative materials (X), is given by

$$G_n = \frac{d D_n}{d \log E_x}$$

Since $d \log E_r = d \log B_o$ this becomes

$$G_n = \frac{d D_n}{d \log B_0}$$

Likewise for B, the characteristic of the positive material (Y), the density gradient is,

$$G_p = \frac{D'_p}{d \log E_y}$$

While for the reproduction curve D

$$G_{mr} = \frac{d \log B_{mr}}{d \log B_0}$$

From the construction of the diagram (Fig. 4), it will be seen that

$$d \log E_y = -d D_n$$

and

$$d \log B_{mr} = -d D'_p = d \log R_p$$

$$\therefore G_n = - \frac{d \log E_y}{d \log B_0}$$

and

$$G_p = -\frac{d \log B_{mr}}{d \log E_y}$$

$$G_n \times G_p = - \frac{d \log E_y}{d \log B_o} \cdot - \frac{d \log B_{mr}}{d \log E_y} = \frac{d \log B_{mr}}{d \log B_o} = G_{mr}$$

$$\therefore G_n \cdot G_p = G_{mr}$$

Now for exact reproduction of contrast, it is necessary that $G_{mr} = 1.0$ and the condition fulfilling this requirement is that the product of the gradient (or slope) of the negative characteristic by the gradient of the positive characteristic shall be equal to unity. If $G_n \cdot G_p$ is greater than unity, a given brightness difference in the object ($d \log B_o$) is rendered in the positive by a brightness difference ($d \log B_{mr}$) greater than that existing in the object and hence the contrast is increased or the contrast scale is expanded. On the other hand, if $G_n \cdot G_p$ is less than unity it indicates that the brightness difference in the positive is less than the corresponding difference in the object ($d \log B_{mr} < d \log B_o$) and it follows that the contrast is decreased, that is, the contrast scale is compressed. Turning now to a consideration of the most convenient method of showing graphically the departure from exact reproduction of contrast, it is found that a curve showing the relation between B_o and the slope (G_{mr}) of the reproduction curve, D, fulfills all the requirements

$$G_e \ (\text{Curve } E) = 1.0 \text{ by construction}$$

$$G_{mr} = \frac{d \log B_{mr}}{d \log B_o} \ (\text{Curve } D)$$

$$\therefore \frac{G_{mr}}{G_e} = \frac{d \log B_{mr}}{d \log B_o} \ (\text{Curve } D)$$

The value of the first derivative of curve D at any point is, therefore, numerically equal to the ratio of the gradient of curve D to that of E, and hence is a measure of the departure from exact contrast reproduction. In Fig. 6 is plotted the value of $\frac{d \log B_{mr}}{d \log B_o}$ (for curve D) as a function of B_o. The log B_o scale is again a duplicate of that in Fig. 4, and the ordinates are gradient values. The condition that $G_{mr} = 1.0$ is that for exact contrast reproduction, and hence the line OX ($G_{mr} = 1.0$) is the curve of exact contrast reproduction. Points lying above this line ($G_{mr} > 1.0$) indicate an increased contrast in the positive while points below ($G_{mr} < 1.0$) correspond to a diminished contrast. In case a given

difference of brightness ΔB_o in the object is rendered by a greater brightness difference ΔB_{mr} in the reproduction, the contrast scale is said to be expanded while the opposite condition is expressed as

FIG. 6.
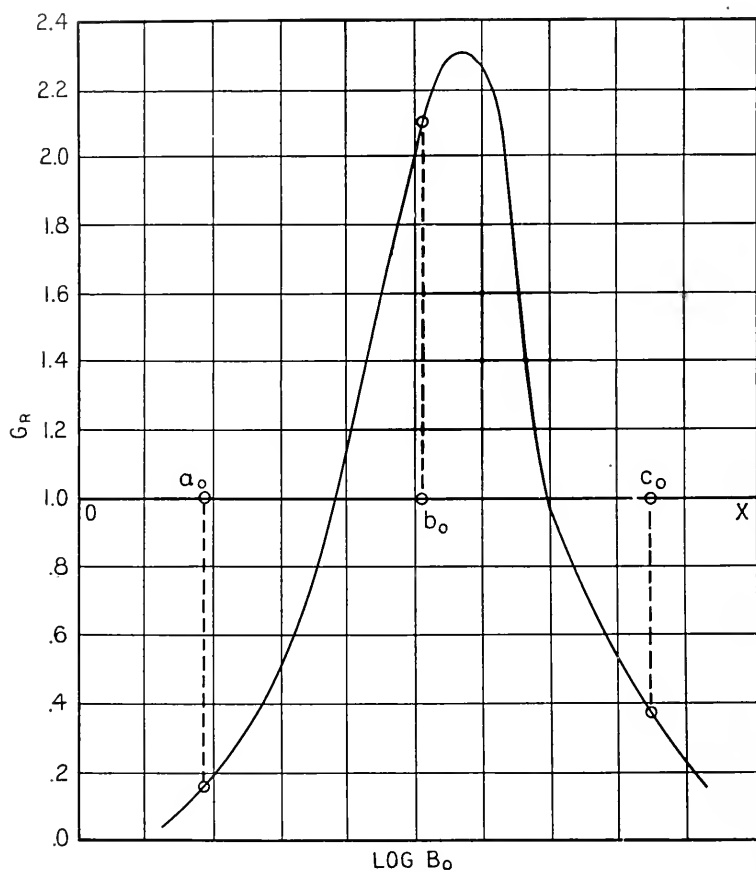
Curve of contrast deviations.

a compression of the contrast scale. These conditions may be expressed mathematically, thus,

1. Increased contrast (Expansion of contrast scale).
$$G_{mr} > 1.0$$
2. Exact contrast reproduction (Normal contrast).
$$G_{mr} = 1.0$$
3. Diminished contrast (Compression of contrast scale).
$$G_{mr} < 1.0$$

In dealing with the straight line portion the gradient values are constant, and hence are direct measures of the contrast reproduction in such regions.

Thus far, no assumption has been made relative to the shape of the curves A and B, the treatment having been of a general nature. In practice it is found that both of these curves may, within the limits of observation, be straight lines over a considerable portion of their lengths. The tangent of the angle which such straight portion makes with the log E axis is designated by the symbol γ, and is equal to the gradient $\left(\dfrac{d\,D}{d\,\log E}\right)$ at any point on the straight line portion. The gradient being constant throughout such straight portions, it is convenient when dealing with tone reproduction by such portions alone to replace the values of gradient by those of gamma.   The relation thus obtained is

$$\gamma_n \;\cdot\; \gamma_p = \gamma_{mr}$$

This it may be noted is the relation deduced by Porter and Slade (*loc. cit.*) which is a special case of the more general relation between the gradient values. The special case is, of course, simpler to deal with and is applicable when the entire reproduction can be obtained by use of the straight line portions, which frequently occurs when the positive is made to be viewed by transmitted light (transparencies, etc.).   In the case of a positive to be viewed by reflected light, it is usually necessary to utilize the entire scale of the positive material, including the curved portions as well as the straight line, and in such cases the special relation ($\gamma_p \cdot \gamma_n = 1.0$, for exact contrast reproduction) is practically useless, it being necessary to employ the more general form, $G_p \cdot G_n = 1.0$.

For that brightness range of the object which can be rendered by the use of deposits in the negative and positive situated on the straight line portion of the characteristic curves of both materials, the above relation may be used. Stating this relation in words, we have for the most general case where the gradient is variable from point to point, that the product of the gradient of the negative by the gradient of the positive is equal to the gradient of the reproduction curve.   This applies only, of course, to the gradient values determined at the corresponding points on the three curves, corresponding points being defined as any three points related to each other as the point b_n, b_p, and b_x, Fig. 4.   Or, for the straight

line portions where gradient is constant and replaceable by gamma, we have that the product of the gamma of the negative by that of the positive is equal to that of the reproduction curve. It may be of interest to note at this point that this is precisely the same relation as that derived by the author in collaboration with Mr. Wilsey (*loc. cit.*), when applying this general method to the problem of measuring the color coefficient photographic deposits. And, since, for exact contrast reproduction, the slope (γ) of the reproduction curve must be unity, the necessary condition is expressed by

$$\gamma_n \cdot \gamma_p = 1.0$$

or

$$\gamma_n = \frac{1}{\gamma_p}$$

It should be borne in mind, however, that this relation holds only for the straight line portion of the curves, while the relation between the values of the differentials G_n, G_p, and G_{mr} is perfectly general and valid for any point regardless of the shape of the curves.

From a complete knowledge of the characteristics of the negative and positive materials, it is now possible to compute the quality of reproduction obtainable. It is also evident from the construction of Fig. 4 if only one of these functions is known, that that of the other can be obtained either graphically or by analytical methods provided an assumption as to the shape of the reproduction curve, D, be made. For instance, if exact reproduction of contrast be desired and a given negative material is to be used, it is evident that curve D must become a straight line having a gradient of unity ($G_{mr} = 1.0$). The shape of the positive characteristic necessary can now be determined. In Fig. 7 is shown the construction which determines this and the resulting shape in case the negative material has the characteristics indicated by curve A. Curve B is the necessary form of the function $D_p = f$ (log E_y). It will be noted that this is of the same general shape as the " reciprocal curves " obtained by Mr. Renwick, which, however, cannot be realized in practice. While Mr. Renwick does not explain the method by which he arrived at the shape of his reciprocal curves, it was undoubtedly by a method somewhat similar to that presented in this paper; at least he arrives at the same general conclusion.

In a similar manner it is possible to determine the required shape of the negative characteristic ($D_n = f$ (log E_x) in order to obtain any desired reproduction with a given positive material. The construction for this is shown in Fig. 8, exact reproduction of contrast being assumed with the positive material represented by the curve B.   Figs. 7 and 8 serve to show the limita-

FIG. 7.

Characteristic of positive material required for exact reproduction.
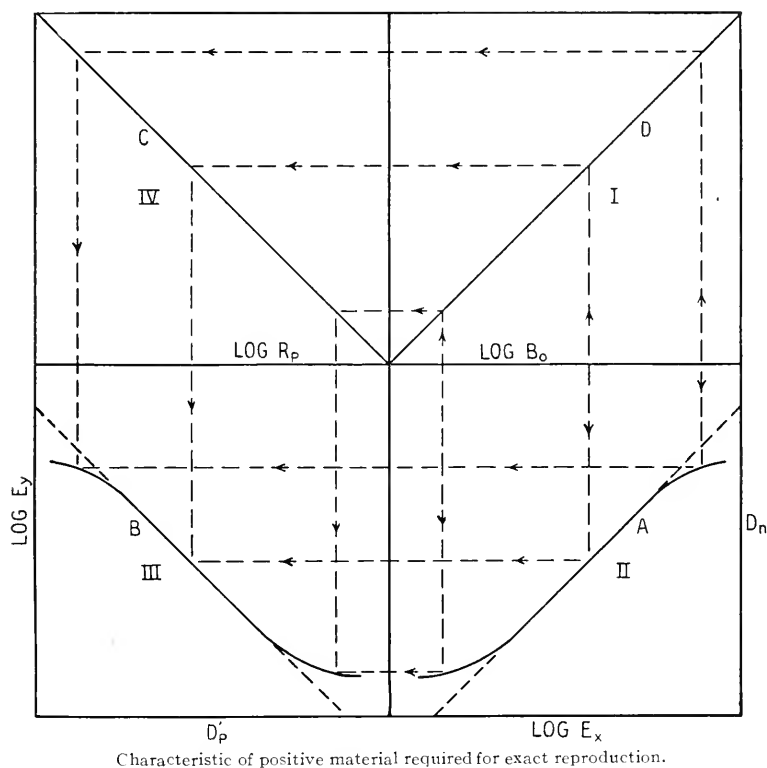
tion of the photographic process in the exact reproduction of contrast, and since the method of construction must be obvious after the detailed discussion of Fig. 4, it will be unnecessary to discuss this further.

Another application of the method which may be mentioned is to the problem of finding the extent to which a negative must be developed in order to render any specified range of brightness values of the object on the straight line portion of the positive

material. In Fig. 9 assume that the range between a_0 and b_0 on the log B_0 scale is to be rendered on the straight line portion of the positive material (Curve B). Locate the point a_p, b_p at the limits of the straight line portion of curve B, and find the positions of points a_n and b_n at the intersections of the vertical and horizontal dotted lines as shown. The line through a_n and b_n is the

FIG. 8.
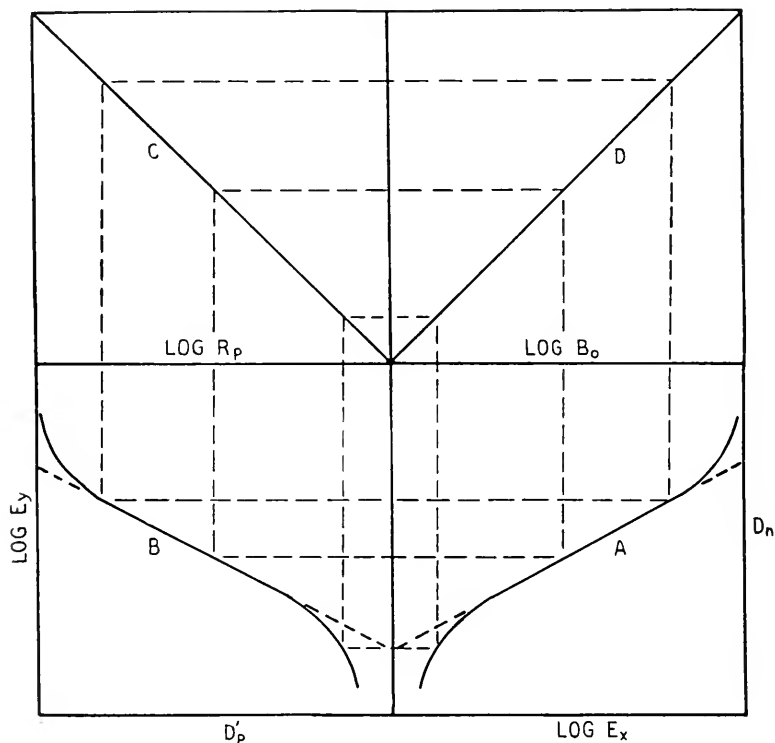
Characteristic of negative material required for exact reproduction.

negative characteristic, A, required, the gradient of which is given by the relation,

$$G_n = \frac{d\, D_n}{d\, \log E_x}$$

or since we are dealing only with the straight line portions for which G_n is constant, $G_n = \gamma_n$

$$\gamma_n = \frac{\Delta\, D_n}{\Delta\, \log E_x} = \frac{\Delta\, D_n}{\Delta\, \log B_0}$$

Where

$\Delta D_n = D_n$ (at b_n) $- D_n$ (at a_n) $=$ Density Latitude (DL_n)

$\Delta \log E_x = \log E_x$ (at b_n) $- \log E_x$ (at a_n) $=$ Exposure Latitude (EL_n)

$\Delta \log B_o = \log B_o$ (at b_o) $- \log B_o$ (at a_o)

$\Delta D_n = -\Delta \log E_y$

Further

$$\gamma_p = \frac{\Delta D'_p}{\Delta \log E_y} = -\frac{\Delta \log R_p}{\Delta \log E_y}$$

and

$$\gamma_{mr} = \frac{\Delta \log B_{mr}}{\Delta \log B_o}$$

Where

$\Delta D'_p = D'_p$ (at a_p) $- D'_p$ (at b_p) $=$ Density Latitude (DL_y)

$\Delta \log E_y = \log E_y$ (at a_p) $- \log E_y$ (at b_p) $=$ Exposure Latitude (EL_y)

$\Delta \log R_p = -\Delta D'_p$

$\Delta \log R_p = \Delta \log B_{mr}$

As shown previously,

$$\gamma_n \cdot \gamma_p = \gamma_{mr}$$

and for exact reproduction of contrast,

$$\gamma_{mr} = 1.0$$

Now from the above relations, it can be shown in the case plotted in Fig. 9 that

$$\gamma_n = \frac{\Delta \log E_y}{\Delta \log B_o} = \frac{\text{Exposure Latitude of Positive Material.}}{\text{Brightness Range Assumed.}}$$

and that

$$\gamma_{mr} = \frac{\Delta D'_p}{\Delta \log B_o} = \frac{\text{Density Latitude of Positive Material.}}{\text{Brightness Range Assumed.}}$$

Also that in general the maximum brightness range of object that can be exactly reproduced is given by $\Delta \log B_o = \Delta D'_p$ (Density Latitude of Positive Material).

These statements assume that the exposure latitude of the negative material is equal to or greater than that of the positive material.

The writer wishes at this point to call attention to the fact that this conclusion, $\Delta \log B_o$ (Max. exactly reproducible) $= \Delta D'_p$, is the same as that drawn by Porter and Slade

(*loc. cit.*) in their recent publication, in which they state that such conclusion is at variance with that reached by the present author, who, in collaboration with Mees and Nutting, published some time ago a paper entitled " The Sensitometry of Photographic Papers" (*Phot. Jour.*, Vol. n. s., 38 (1914) p. 342). This paper, as indicated by its title, dealt with methods for the determination of the

FIG. 9.

Determination of the negative contrast required for specified results.

sensitometric constants of photographic printing papers, and did not pretend to deal with the problem of tone reproduction. A comparison of the characteristics of a negative material and a printing paper was made only for the sake of emphasizing the marked difference between them. Quoting the sentences in question we state : " But the maximum values of latitude met with in papers is of the order of .75 in log E units, or 1 to 5.6 in exposure

units. The paper then will only render correctly a range of bright-
ness ranging from 1 to 5.6; hence it is obvious that in order to
render a *negative* having a range any wider than 1 to 5.6 in
transmission it is necessary to utilize portions of the characteristic
curve lying outside the ' latitude ' of the paper and thus depart
from correct proportional rendering." It may be possible that
the use of the word " brightness " in the first phrase (which was
used as specifying the intensity factor of the light permitted by
the negative to act upon the paper during printing) may have been
misinterpreted. In the next sentence, however, it is specifically
stated that a negative " having a range wider than 1 to 5.6 in
transmission " was being considered. The word " transmission "
should certainly have corrected any misapprehension arising from
our use of the word " brightness." Moreover, in the following
sentence of our paper, it is again clearly stated that the point under
consideration is the "range of densities in the negative that can
be correctly rendered," with no mention of the object brightness
represented by such negative densities.

Returning again to further consideration of Fig. 9, it is
evident if the range of brightness values ($\Delta \log B_o$) is greater
than the density latitude (DL_y) of the positive material being used
that it will be impossible to reproduce exactly the contrast of the
object over the entire range, $\Delta \log B_o$.

However, it is possible to compress this tone scale of the object
so that it can be proportionately rendered on the straight line
of the positive material. Proportional rendering is defined by the
relation, $d \log B_o = k \cdot d \log B_{mr}$, where k is a constant known as
the proportionality factor.

$$k = \frac{d \log B_o}{d \log B_{mr}} = G_{mr}$$

or

$$k = \gamma_{mr} \text{ (For straight line portion).}$$

γ_{mr} may, therefore, be considered as the proportionality factor
indicating the magnitude of the expansion or compression of the
contrast scale. Thus, if $\gamma_{mr} = .5$ it indicates that a given bright-
ness interval of the object has been compressed to one-half of its
value in the reproduction, that is, the contrast has been decreased
by one-half. The same applies to an expansion of the scale re-
sulting in an increased contrast in the reproduction, the value

of γ_{mr} being again the proportionality factor. This, then, may be defined as that value by which a given brightness interval in the object must be multiplied in order to obtain the corresponding brightness interval in the reproduction.

It is evident from an inspection of Fig. 9 that the range of object brightness values which can be reproduced in correct proportion is limited only by the exposure latitude (EL_x) of the negative material. Since a negative material may have a latitude of 1 to 128 (in exposure units) or even more, it is evident that the great majority of objects may be rendered proportionally on the straight line portion, for measurements show that the contrast range seldom exceeds this value (1 to 128).

The applications of the methods outlined to practical problems are too numerous to mention in detail at this time. However, a specific example, Fig. 10, is shown. This illustrates the reproduction resulting from the use of obtainable negative and positive materials, the characteristic curves of which have been carefully determined by sensitometric measurements in this laboratory. The data, essential to this discussion, relative to the materials are as follows:

The negative material:

$$EL_x \text{ (Exposure latitude)} > 2.0 \text{ (in log } E\text{)}.$$

$$\log i = \overline{2}.5$$

$$\gamma\infty > 1.00$$

The positive material (a developing-out paper).

E_s	(Standard Exposure)	$= 100,000$ (m.c.s.)
γ_∞		$= 1.34$
EL_y	(Exposure Latitude)	$= .77$ (in log E)
ES_y	(Exposure Scale)	$= 1.50$ (in log E).
DL_y	(Density Latitude)	$= 1.06$
DS_y	(Density Scale)	$= 1.43$
D_{max}	(Maximum Density)	$= 1.45$
R_h	(Reflecting power of fog strip) $= .80$

Let it be assumed that the highest object brightness is 1000 (apparent meter candles), and that this brightness is to be rendered in the positive by a just perceptible density ($D = .01$ (approximately), $R_p' = .02$).

In order to illustrate the effect of the contrast (γ) to which the negative is developed upon the quality of the resulting repro-

duction, three different negative characteristics are plotted differing only in the value of gamma. The gamma values chosen are for A_1, $\gamma_n = .75$; for A_2, $\gamma_n = .87$; and for A_3, $\gamma_n = 1.00$.

The three curves B_1, B_2, and B_3 represent the characteristic of the positive material, these being exactly similar in shape but plotted in different position so that the condition of a just per-

FIG. 10.
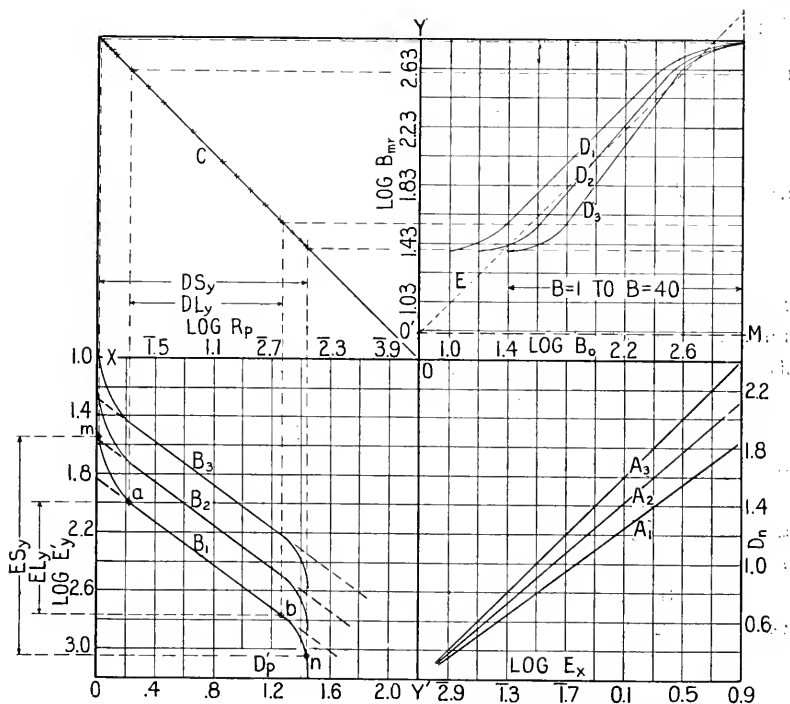
Objective reproduction obtainable with specified materials and conditions.

ceptible density for the highest light may be fulfilled in all cases. The values on scale of log E'_y are arbitrary and a constant which differs for each of the curves B_1, B_2, and B_3 is applied in order to determine the value of log E_y, from which the absolute value of printing exposure necessary may be computed, the relation being log $E'_y + C = \log E_y$.

Curve C is the dummy used for transferring the points on the scale of log R_p to the log B_{mr} scale. Under certain conditions

(previously specified) this curve becomes the actual subjective relative-contrast function. The points on this curve merely illustrate the way in which the construction points are located and apply to the construction of Curve D_1. The curves D_1, D_2, and D_3 are reproduction curves obtained by the graphic solution as previously outlined, D_1 being that obtained by the use of A_1 and B_1, etc. Since the positive material has a straight line portion, each reproduction curve is straight over part of its length. The gamma relation corresponds to the expression $\gamma_p \cdot \gamma_n = \gamma_{mr}$.

Therefore for D_1

$$\gamma_{mr} = 1.34 \cdot .750 = 1.01$$

for D_2

$$\gamma_{mr} = 1.34 \cdot .91 = 1.17$$

and for D_3

$$\gamma_{mr} = 1.34 \cdot 1.00 = 1.34$$

In Fig. 11 are plotted the first derivatives of the three reproduction curves D_1, D_2, and D_3 showing the magnitude of the departure from exact contrast rendering for each case, the straight line at $G_{mr} = 0$ (Fig. 11) being the curve of exact contrast reproduction. The curve E (Fig. 10) is the line of exact contrast reproduction, and so located as to represent also the best approximation to exact reproduction of brightness in case of the reproduction curve D_2. The log B_{mr} scale is established on the assumption that I_p is of the magnitude indicated by the position of O'.

Now applying the equation for the value of t_x, the negative exposure time,

$$\log t_x = \log E_x - (\log B_o + \log K_x).$$
$$\text{Let } \log B_o = 2.6$$
$$\text{Then } \log E_x = 0.5$$

And assume as a value for the constant of the image forming system

$$K_x = .01, \ \log K_x = \bar{2}.0$$

Solving we obtain

$$t_x = .0126 \text{ sec.}$$

This then is the time necessary in exposing the negative material.

The standard exposure, E_s, is defined (Jones, Mees, and Nutting, *l. c.*) as that exposure in meter-candle seconds which will just print through a density of 2.0. Since a density of 2.0 transmits .01 of the incident illumination it follows, in the present case, that an exposure of .01 × 100,000 mcs. or 1000 mcs. will produce a just perceptible deposit on the positive material used.

FIG. 11.
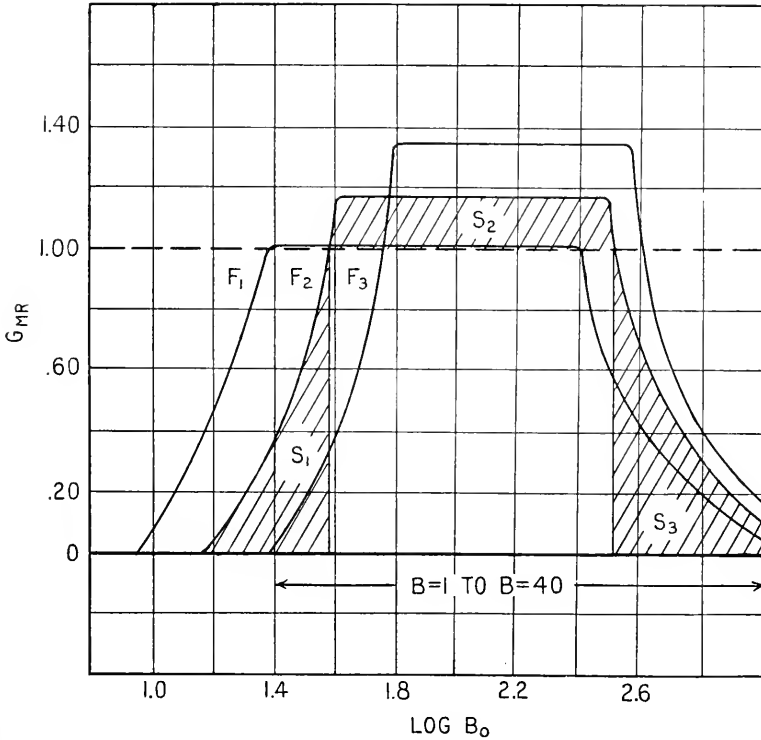
Contrast deviations occurring in curves in Fig. 10.

Therefore at the point where

$$\log E'_y = 1.55, \; \log E_y = \log 1000 = 3.0$$
$$1.55 + C = 3.0$$
$$\therefore C_1 = 1.45$$

Likewise,

$$C_2 = 1.73$$
$$C_3 = 2.01$$

Now from the equation (p. 53) giving the printing exposure necessary,

$$\log t_y + \log I_n = \log E_y + D_n$$
$$\text{Where } D_n = 1.4$$
$$\log E_y = 2.0 + 1.45 = 3.45$$
$$\therefore \ \log t_y + \log I_n = 3.45 + 1.4 = 4.85$$
$$\text{or } t_y \cdot I_n = 70.800$$
$$\text{Hence, if } I_n = 1000 \text{ m. c.}$$
$$\text{For negative } A_1, \ t_y = 70.8 \text{ sec.}$$
$$\text{Inserting values of } C_2 + C_3 \text{ we obtain}$$
$$\text{For negative } A_2, \ t_y = 135 \text{ sec.}$$
$$\text{and for } A_3, \ T_y = 250 \text{ sec.}$$

Since R_b for the paper used is .8, $\log R_b = \bar{1}.90$. Therefore the scale of $\log R_p$ is so established that at any point on the scale,

$$\log R_p = \bar{1}.90 - D'_p$$

In this case the $\log B_{mr}$ scale is established directly on the OY axis. This is found to be more convenient in some cases than to establish this scale on the OX' axis as indicated previously, especially when it is desirable to make the curve of absolute reproduction occupy some particular position relative to the reproduction curve. In this case the curve E was drawn in the desired position, and from the point O' thus established the values of $\log B_{mr}$ necessary to make the curve E that of absolute reproduction was determined, the condition being that

$$\log B_{mr} \text{ (at } O') = \log B_o \text{ (at } O)$$
$$\log B_o \text{ (at } O) = .8 = \log B_{mr} \text{ (at } O').$$

Now from the equation,

$$\log I_p = \log B_{mr} - \log R_p$$

it is possible to find the value of I_p which is necessary to illuminate the positive to satisfy the relation between the $\log R_p$ and $\log B_{mr}$ scales as established.

The point on the $\log B_{mr}$ scale, for instance, corresponding to the point where $R_p = \bar{2}.3$ is $\log B_{mr} = 1.23$.

$$\therefore \ \log I_p = 1.23 - (\bar{2}.3)$$
$$2.93$$
$$I_p = 851. \text{ (meter candles)}$$

Now, with this illumination on the positive obtained by use of negative A_2 the material reproduction will be as indicated by the curve D_2. In the region lying below the line E the areas will be less bright than the corresponding areas of the object, while in those above the contrary will be the case.

By decreasing the illumination the curve E can be made to coincide with the straight line portion of reproduction curve D_1, and much better brightness reproduction obtained for that particular positive in the middle tones, although the departure in the highlights will be greater than for the curve D_2 with the illumination specified. In practice it is not necessary to obtain exact reproduction of brightness since the eye is an organ of variable sensibility, and a low actual brightness may excite the same sensation as one of high value if the adaptation level of the eye be of the proper value.

The location of the points m and n (Fig. 10) should be mentioned at this point. They are the points which limit the scale of the positive material, Y, and are located at the points on the curve of that material where the term $\frac{D_p}{d \log E_y}$ has a certain assumed value. The value assumed previously was .2 and occurs in the particular case of the printing paper used in this illustration at the points where $D = .01$ and $D = 1.44$. The points a and b are located at the extremities of the straight line portion, and their positions determine the values of the exposure latitude, EL_y, and the density latitude, DL_y. Since the gradient, G_{mr}, of the reproduction curve is equal to the product of G_n and G_p, it follows that the gradient of the reproduction curves at points corresponding to m and n will depend on the value of G_n, being greater for high values of G_n and *vice versa*. Practically, however, it many be considered that the scale of the reproduction curve is limited by the points corresponding to m and n as shown by the dotted construction, although in extreme cases exceptions to this rule may be necessary. Likewise the latitude of the reproduction curve may be considered as limited by the points corresponding to a and b. According to this it is evident from the construction that the following relation exists:

Defining as follows:

Object Latitude (OL) = Range of brightness values of the

object rendered on the straight line portion of the reproduction curve.

Object Scale (OS) = Range rendered on scale of reproduction curve.

$$OL = \frac{EL_y}{\gamma_n}$$

$$OS = \frac{ES_y}{\gamma_n}$$

Further if,

BL_{mr} = Brightness Latitude of the Reproduction.
BS_{mr} = Brightness Scale of the Reproduction.

Then:

$$BL_{mr} = DL_y$$
$$BS_{mr} = DS_y$$

It may be of interest to tabulate some of the actual values obtained in this curve.

TABLE II.

Negative	γ_n	γ_{mr}	OL	OS
A_1	.75	1.01	1.03	2.00
A_2	.87	1.17	.89	1.73
A_3	1.00	1.34	.77	1.50

Other useful relations may be desired, but since their importance depends upon the particular problem being dealt with, further consideration will not be given them at this time.

Turning now to the derivatives plotted in Fig. 11, their interpretation will be considered briefly. By integrating the area inclosed by each curve and the line of G_{mr} equal to zero, the mean value of gradient over the entire scale of object brightness rendered can be determined. These values are tabulated in column B (Table III).

TABLE III.

Negative	γ_n	B	C	D
A_1	.75	.71	.30	.25
A_2	.89	.83	.37	.32
A_3	1.00	.95	.45	.48

The mean deviation from the line of exact contrast reproduction can be obtained by integrating the partial areas as indicated by the shaded areas (S_1, S_2, and S_3) which apply to curve F_2, adding the values thus obtained together and dividing by the

value of OS.   The mean deviations thus determined are given in column C (Table III).

The deviations thus obtained apply, of course, to different ranges of brightness in the object. However, if it is desired to determine the mean deviation from $G = 1.00$ for a given object having a fixed contrast, it is only necessary to limit the areas considered to the specified brightness range. For instance, let us determine the mean deviation for each reproduction of contrast for an object having a range of $B = 1$ to $B = 40$. The vertical line drawn through the point $\log B_0 = 1.4$ now limits the areas which must be integrated in order to find the desired deviation. The values obtained for the three curves are given in column D (Table III). It is thus possible to determine the magnitude of the departure from exact reproducion of contrast of any desired range of object brightness values, when reproduced by means of negative and positive materials of known characteristics.

From a consideration of Fig. 10, a conclusion of considerable importance in practical work may be drawn. This relates to the problem of choosing the printing paper best adapted to a given negative or the inverse problem of making a negative of the proper quality for printing on a given printing paper. Considering Curve B, it will be seen that the useful portion is limited by the points m and n.   On portions of the curve lying outside of these limits the gradient $\dfrac{d D'_p}{d \log E_y}$ is so small as to be practically useless in the reproduction of differences in E_y. Now in practice it is, in the great majority of cases, desirable to render the deepest shadow (lowest brightness) of the object by the maximum useful density of the positive material, and the highest light (greatest brightness) by the minimum useful density of the printing material, and at the same time to render all of the brightness differences of the object as density differences in the finished print. If the density in negative by which the highest light of the object is rendered be designated by the symbol $D_n max$, and that negative density which renders the deepest shadow be designated by $D_n min$, it is evident in order to fulfill the condition stated in the previous sentence that $D_n max. - D_n min. = ES_y$. The quantity $(D_n max. - D_n min.) = DS_n$ is termed the " density scale of the negative " and applies to a particular negative. This term (DS_n) should not be confused with the similar term DS_x which applies to the nega-

tive material itself with a meaning exactly parallel to that of DS_y as applied to the positive material.

From a consideration of Fig. 10, it will be seen if the negative and printing paper be such that $DS_n = ES_y$, that all of the density differences in the negative will be rendered as density differences in the print, and further, that the maximum negative density will be rendered as the minimum useful density of the printing material while the minimum negative density will result in the maximum useful density in the print. Such procedure, of course, results in the loss of contrast in the extreme shadows and highlights due to the shape of the characteristic curve of the printing paper, even though (as is usually possible) all of the object brightnesses are rendered on the straight line portion of the negative curve. Of two printing papers having identical values of ES_y (and equal to the value of DS_n for the negatives considered), the better result will in general be obtained by use of the one of which the characteristic curve most closely approximates to a straight line between the points m and n. While in some special cases better results may be obtained by some other procedure, it is undoubtedly true that in general the most favorable relation between negative and printing paper is that the " density scale " DS_n of the former shall be as nearly as possible equal to the " exposure scale " DS_y of the latter.

Since it is not the primary object of this paper to deal with particular cases, but rather to outline the general theory of the subject, the discussion of the objective phase will be closed at this point, leaving the application to practical problems for treatment in subsequent papers. Moreover, a final evaluation of the quality of a reproduction cannot be made without a consideration of the subjective phase of the problem, and this will now be treated.

THE SUBJECTIVE PHASE.

Turning now to a consideration of the subjective phase, it will be well to discuss the significance of the curves shown in Fig. 3. These contain the data relative to the visual sensitivities necessary for the evaluation of the subjective relative-contrast function. Curve A gives the relation of the sensation to the stimulating brightness. Equal increments on the Y axis correspond to equal increments in the sensation and the brightness intervals which give rise to these sensation steps can be determined from this curve. The shape of this function could be established by

direct experiments, but since such a process is extremely laborious, it is customary to arrive at the same end by other means.   The curve B, the contrast sensibility, is the first derivative of the sensation curve, hence, if the sensibility be measured and the curve B plotted, the sensation curve may be obtained by integration.   The sensibility at a given adaptation level is determined by measuring the least difference in brightness perceptible under the specified conditions.   The least perceptible difference, ΔB, expressed as a fraction of the brightness at which it is determined, is a direct measure of the sensibility of the eye to contrast or brightness difference.   The data from which the curve B is plotted are given in Table IV, and are from the work of Nutting and Blanchard (*loc. cit.*).   The ordinate of curve B at any point is therefore equal to the slope of the curve A at the same value of B.   Thus, if S be the sensation, $\dfrac{d\,S}{d\,\log B} = \dfrac{B}{\triangle B}$.   The values of the ordinates of the sensation curve are in terms of sensation units, and the construction of such a sensation scale is based on the assumption that a just perceptible difference at any point on the sensation scale is equal to a just perceptible difference at any other point.   The basic unit upon which this scale is established is therefore the least perceptible brightness difference.

It will be noted from the data in Table IV that the range of brightness over which the eye operates is enormous, from $B =$ .000001 to $B = 10000$ millilamberts, a range of 1 to 10,000,000,000, while for the photographic plate the corresponding range is but 1 to 2000 (approximately).   This extreme range in case of the eye is due largely to the fact that the retina changes in sensibility with the intensity of the incident radiation.   This property of variable sensibility has been likened to that of an ammeter equipped with a shunt whose resistance decreases as the current increases.   The diameter of the pupil is but a very small factor in the sensibility change since it varies in area over a range of but 1 to 64.   It should be pointed out that the curves in Fig. 3 are similar in shape to those given by Renwick (*loc. cit.*) but that the absolute values of log brightness are very different.   This is due undoubtedly to the uncertainty in the value of the unit used by König, from whose data the curves in question were plotted. Blanchard (*loc. cit.*) has discussed the question and has computed the probable value of König's unit as being .004 ml. (approxi-

mately). The millilambert is the c. g. s. unit of brightness, and is equivalent to a brightness of ten meter candles or .93 foot candles. The region of maximum sensibility is therefore from 3 to 250 foot candles (approximately), instead of from 20,000 to 400,000 as indicated by the curves published by Renwick. Since the function of use in relating subjective reproduction to the objective contrast is obtained by using the ratio of the gradients at two points on the sensation curve, the units in which the curve is plotted are not of importance. However, in order to determine the sensibility for a given adaptation level, it is important that the correct abscissæ value be used.

Now, if we consider a specified brightness difference in the object viewed with the eye adapted to some brightness level A_o, it is possible from curve A (Fig. 3) to find the corresponding sensation difference; and if the brightness difference between the corresponding areas of the material reproduction be known, together with the adaptation level (A_{mr}) of the observer viewing this material reproduction, it is possible to determine also the

TABLE IV.

Visual Sensitometric Data

Field Brightness	Difference Fraction	Discrimination Factor	Threshold Limit
0.000001	(1.00)	1.0	0.00000093
0.00001	(0.66)	1.5	0.0000042
0.0001	0.395	2.5	0.000019
0.001	0.204	4.5	0.000087
0.01	0.078	12.8	0.00039
0.1	0.0370	27.0	0.00174
1.0	0.0208	48.2	0.0081
10.0	0.0174	57.5	0.036
100.0	0.0172	58.1	0.28
1000.0	0.0240	41.7	2.15
10000.0	(0.048)	(20.9)	(232.0)

magnitude of the resulting subjective contrast. A comparison of the magnitudes of these two contrast values namely: (a) the subjective contrast resulting from observation of the object at a given adaptation level, which subjective evaluation it is convenient to refer to as the subjective object; and (b) the subjective contrast due to the observation of the material reproduction at a specified adaptation level, which subjective evaluation will be termed the

'subjective reproduction; determines the exactness with which the subjective sensation resulting from the observation of the object is reproduced by observation of the material reproduction (the illuminated positive) under the conditions specified. It is also possible by similar methods to determine the magnitude of the contrast necessary, at any point in the tonal scale of the material reproduction, for the exact reproduction of the subjective contrast of the object, assuming, of course, that the values of A_o and A_{mr} are known

A_o = Adaptation level while observing object.

A_{mr} = Adaptation level while observing material reproduction.

For instance, in Fig. 12 consider an increment of brightness, Δ $\log B_1 = \log B_1 - \log B_1'$, for which the corresponding increment in the sensation is $\Delta S_1 = (S_1 - S_1')$. At any other point take a second increment in sensation $\Delta S_2 = (S_2 - S_2')$ such that $\Delta S_1 = \Delta S_2$. Let the increment in $\log B$, corresponding to ΔS_2, be represented by Δ $\log B_2 = (\log B_2 - \log B_2')$. Assume that the increment $\Delta \log B_2$ applies to some point in the object, and that the value of $\log B_2$ fixes the adaptation level of the observer looking at that object, while for the material reproduction the adaptation is conditioned by the value of B_1

$$A_o = B_2$$
$$A_{mr} = B_1$$

Now the average slope of the curve (Fig. 12) over the range $\Delta \log B_2$ is given by,

$$\text{Slope (2)} = \frac{\Delta S_2}{\Delta \log B_2}.$$

And the average slope over the interval $\Delta \log B_1$ is likewise,

$$\text{Slope (1)} = \frac{\Delta S_1}{\Delta \log B_1}.$$

Since $\Delta S_1 = \Delta S_2$ it follows that

$$\frac{\text{Slope (2)}}{\text{Slope (1)}} = \frac{\Delta \log B_1}{\Delta \log B_2}$$

But the average slope of the sensation curve over any given interval is given by the average value of the ordinate, D, of the contrast sensibility curve (Curve B, Fig. 3) over the same in-

terval. Hence, we may express the values of the slope by the corresponding values of D, and equation becomes

$$\frac{\text{Average } D_2}{\text{Average } D_1} = \frac{\Delta \log B_1}{\Delta \log B_2}$$

or

$$\Delta \log B_2 = \Delta \log B_1 \cdot \frac{\text{Average } D_1}{\text{Average } D_2}$$

FIG. 12.

LOG B
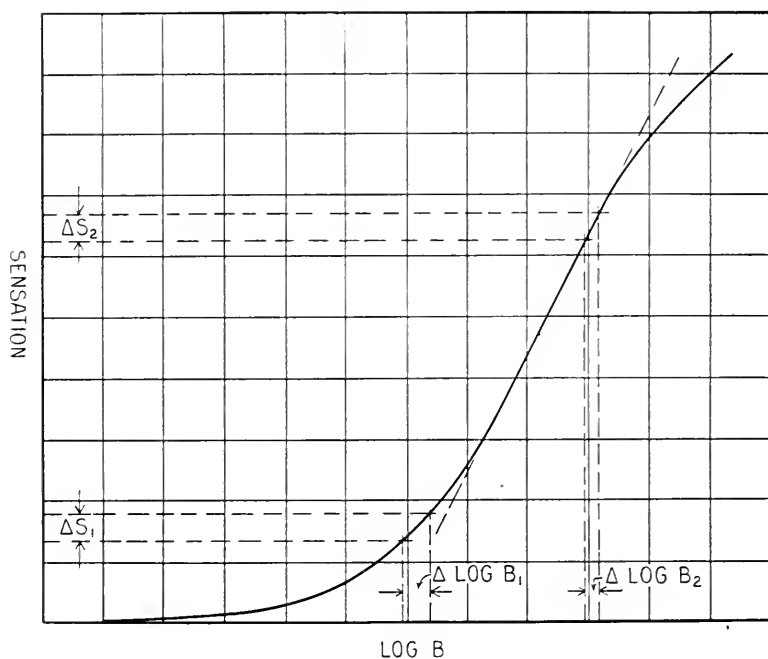
The relation between sensation and stimulus.

It is evident, therefore, if $\Delta \log B_2$ be the objective brightness difference at some point in the object that the equation will give the value of the $\Delta \log B_1$, the objective brightness difference necessary in the photographic reproduction for the exact reproduction of subjective contrast. In the case illustrated, the interval $\Delta \log B_2$ is less than the interval $\Delta \log B_1$, thus indicating that a greater objective contrast in the reproduction will be required to reproduce the subjective contrast due to the smaller objective contrast in the object.

It is well known that other factors than the brightness of the area upon which the attention is fixed (foveal image) influence to some extent the adaptation level of the eye at any instant. Such factors include the brightness of the surrounding objects (*i.e.*, the peripheral images), and the length of time during which the attention has been fixed on the area considered. In practice, however, the picture being observed occupies a very considerable portion of the field of vision, and, further, in the great majority of such pictures the actual range of brightness is relatively limited. This is especially true of surfaces viewed by reflected light. Further, under the majority of conditions, the field of vision not filled by the reproduction being considered does not contain any area contrasting extremely with the brightness of the reproduction. It seems reasonable, therefore, to assume that the adaptation level will be fixed in practice by the brightness of the reproduction itself, and likewise that the level when viewing the object will be conditioned by the object considered.

The question then arises as to what particular brightness in object and reproduction will determine the adaptation level in each case. Considering the reproduction as a reflecting surface, the average range of brightness may be taken as 1 to 40 (1.6 in $\log B_{mr}$), which, even at the steepest part of the sensibility curve (Fig. 3) does not correspond to an excessive change in value of D. The change in adaptation as attention travels from highlight to shadow probably is not so great as that indicated by the brightness range, being limited to some extent by the stabilizing effect of the peripheral images as well as to the time lag of adaptation behind the changing foveal stimulus. It seems logical, therefore, to assume that A_o and A_{mr} are conditioned by the average brightness of object and material reproduction, and this assumption will undoubtedly hold for a large percentage of the normal cases, although it may be necessary, under extreme conditions, to take into account the change in adaptation (and consequently in the value of D) which occurs as attention shifts from an area of one brightness to that of another.

As a simplifying condition, let us, therefore, assume that the adaptation level is conditioned by a brightness of the object and reproduction respectively half-way between (on the $\log B$ scale) the highest and lowest brightness considered.

Let the values of the various factors be designated by:
  For the object:

  A_o = Adaptation Level for Average B_o.
  D_o = Sensibility.

For the reproduction:

  A_{mr} = Adaptation Level for Average B_{mr}.
  D_{mr} = Sensibility.

Now in the equation previously given,

$$\frac{\text{Average } D_2}{\text{Average } D_1} = \frac{\Delta \log B_1}{\Delta \log B_2}$$

let the numerical subscripts be replaced by the subscript letters indicating the application of the terms to particular values, thus,

$$\frac{\text{Average } D_o}{\text{Average } D_{mr}} = \frac{\Delta \log B_{mr}}{\Delta \log B_o}$$

By allowing these finite increments to approach zero as a limit, we may replace the average values of D by values of the slope of the contrast sensibility curve at a point and obtain the expression

$$\frac{D_o}{D_{mr}} = \frac{d \log B_{mr}}{d \log B_o}$$

Since previously an assumption of equality of subjective contrast (sensation increment) was made, this equation is a statement of the conditions necessary for the exact reproduction of the subjective contrast.

Now the value of $\frac{D_o}{D_{mr}}$ gives the slope of a curve which if plotted in Quadrant *I*, Fig. 4, would be the line of exact subjective reproduction of objective contrast. In the graphic solution, however, it is more convenient in plotting the reproduction curve D, and also in the later interpretation of the results, to retain the line E (of which the gradient is unity) as the line of exact contrast reproduction, and to alter the position of the points on the scale on the line O so that the reproduction curve plotted therefrom will be the curve of actual subjective reproduction, this alteration of position being an expansion or compression of the points on the scale in the case of constant values for the adaptation levels (A_o and A_{mr}), or a distortion of their distribution in case

such values are variable.   It is quite possible to obtain the final
evaluation of the exactness of reproduction as a comparison
between the contrast values of the subjective object and the sub-
jective reproduction (see Table I, Items I and X), but in view of
the fact that the starting point in any tone reproduction problem
must be the objective brightness values of the object, it seems more
logical to make these values the primary base of the computation
and to express finally the departures from exact reproduction in
terms of these physically measured values of object brightness.
This necessitates the evaluation of the subjective contrast of the
reproduction in terms of the subjective contrast of the object, and
a final expression of this complex relation as a function of the
object brightness B_o. The final comparison must therefore be
made between the actual measured (objective) contrast values of
the object and the corresponding contrast values of the subjective
reproduction evaluated in terms of the subjective object.   The
scale on which the points representing the various areas of the re-
production as evaluated in terms of this relative subjective con-
trast function, must occupy the line OY in order that the curve
representing the final reproduction may be graphically constructed
with values of B_o as abscissæ. The required scale constructed on
line OY will be termed the log B_z scale, and the relative subjective
contrast function which is used to determine the distribution of
the points on the log B_z scale will be referred to as the Z function,
and its gradient will be designated by G_z.

   Now in order that the line E (in Quadrant I), having a slope
of unity, shall be the line of exact subjective contrast reproduc-
tion, it is necessary that its slope or gradient be given by the
expression $G_e = \dfrac{\triangle \log B_z}{\triangle \log B_o}$ where $\triangle \log B_o$ is some increment on
the log B_o scale for which the corresponding interval in the sub-
jective reproduction is $\triangle \log B_z$. Let the scale of log B_{mr} on line OY
(Fig. 4) be replaced by a scale of log B_z (Fig. 13).   This
can be accomplished by replacing the dummy curve C (Fig. 4),
by the new function which gives the relation between the material
(objective) reproduction and the subjective reproduction. This
subjective reproduction is itself a complex function containing
the relation between the subjective evaluation on the object and
subjective evaluation of the material reproduction.   These evalua-
tions are conditioned by the sensibility of the eye to brightness dif-

ferences (contrast) at the time of observing the object and when viewing the reproduction. This relation, the relative subjective contrast function, can be constructed graphically, but the consideration of this will be omitted. It is sufficient for the present purpose to state that the gradient of this curve, which must be

FIG. 13.
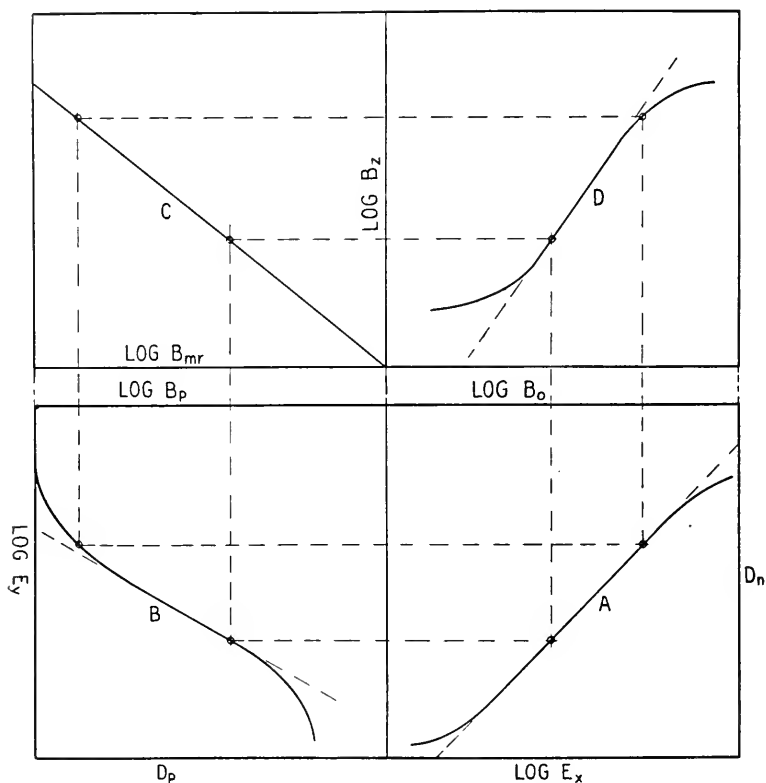
Special case of the complete solution including subjective phase.

substituted for the dummy curve thus far used, is equal to the reciprocal of the ratio of the values of D_o to D_{mr}. Let G_z indicate the gradient of the relative subjective contrast function which from this point on will be used instead of the dummy curve, having an arbitrary gradient equal to unity.

$$G_z = \frac{D_{mr}}{D_o}$$

This procedure also makes it possible to establish on the line OY the scale log B_z (Fig. 13), for which the points located by the usual construction methods will represent the relative subjective brightnesses corresponding to the various areas of the ob- ject considered.

Now if

$$D_o = D_{mr}$$
$$G_z = 1.0 = G_d$$

This is the gradient thus far used in the construction of the curve C. It is evident, therefore, if average B_o and average B_{mr} are such that they fall between the limits (Fig. 3), log $B = 0.5$ ($B = 3.2$ ml.) and log $B = 2.2$ ($B = 166$ ml.) that the subjective reproduction of contrast will be identical with the material reproduction curves already discussed.

If, however, the brightness, B_o, of the object and the conse- quent adaptation level, A_o, of the observer viewing that object is relatively high, while the brightness of the material reproduction, B_{mr} (the illuminated positive), and the corresponding adaptation level, A_{mr}, is low, the subjective reproduction will be different from the objective reproduction. In this case the contrast sen- sitility D_o is greater than D_{mr} and hence the gradient, G_z, of the relative subjective contrast curve is less than unity.

$$G_z = \frac{D_{mr}}{D_o}$$

The reproduction curve, D, constructed in the usual way will also have a decreased gradient. This indicates that under such con- ditions a loss of contrast occurs due to the subjective factors, and in order to obtain exact subjective reproduction it will be necessary to enhance the objective contrast in material reproduction, in order to compensate for the loss due to the subjective effect. It is evident from these considerations that a picture of a brilliantly light scene, which is to be viewed under relatively low illuminations, such as exist in interiors at night should be somewhat more con- trasty than the scene itself. That is, best subjective reproduction will be obtained by a positive in which the actual objective contrast is somewhat enhanced. This condition may be stated sym- bolically thus:

If,

D_o is greater than D_{mr},
G_z is less than 1.0.

When G_z is less than unity there will be a loss of contrast due to the subjective factors.

On the other hand if,

$$D_o \text{ is less than } D_{mr},$$
$$G_z \text{ is greater than 1.0,}$$

and there will be an enhancement of contrast due to the subjective factors. When G_z is greater than unity the slope of the relative subjective contrast function (Curve C is Quadrant IV) is greater than unity, and the gradient of the resulting reproduction curve D (Quadrant I) is increased accordingly.

Now from a consideration of Fig. 13 it will be seen that:

$$G_n = \frac{d\ D_n}{d\ \log E_x} = \frac{d\ D_n}{d\ \log B_o}$$

$$G_p = \frac{d\ D'd}{d\ \log E_y} = - \frac{d\ D'd}{d\ D_n} = \frac{d\ \log B_{mr}}{d\ D_n}$$

$$G_p \cdot G_n = \frac{d\ \log B_{mr}}{d\ \log B_o}$$

$$G_z \text{ (Curve } C) = \frac{d\ \log B_z}{d\ \log B_{mr}} = \frac{D_{mr}}{D_o}$$

$$G_r \text{ (Curve } D) = \frac{d\ \log B_z}{d\ \log B_o}$$

$$G_n \cdot G_p \cdot G_z = \frac{d\ \log B_{mr}}{d\ \log B_o} \cdot \frac{d\ \log B_z}{d\ \log B_{mr}}$$

$$= \frac{d\ \log B_z}{d\ \log B_o} = G_n$$

$$\therefore G_n \cdot G_p \cdot G_z = G_r$$

For the straight line portions of the curves, if such exist,

$$\gamma_n \ \gamma_p \cdot \gamma_z = \gamma_r$$

Therefore if any three of these four functions involved be known or are assumed, the fourth may be determined. The line E as before is the curve of exact reproduction of contrast, and the curve D is the reproduction obtained under the specified conditions. Deviations may be determined as in case of the solution for the objective phase, and the results will indicate the departure

from the exact reproduction of subjective contrast. It should be noted that this construction gives direct comparison between the objective values of brightness and the relative subjective equivalent in the reproduction. That is, the comparison is not between the subjective impression of the object and the subjective impression due to the reproduction, although this comparison can easily be made if such seems desirable. The procedure adopted is such that all of the subjective factors are introduced by use of the curve C, the relative subjective contrast function, such procedure in effect is the evaluation of the subjective reproduction in terms of the subjective contrast in the object itself.

Now in case it is considered necessary, by reason of the existing conditions, to take into account the change of adaptation with shift of attention from highlight to shadow, this can be accomplished by computing for each pair of object and reproduction brightnesses the value of the ratio $\frac{D_{mr}}{D_o}$, and from the values thus obtained plotting a curve which is then used as the relative subjective contrast function. The curve C may not, under such circumstances, be a straight line, but will vary in slope as indicated by the computed values of $\frac{D_{mr}}{D_o}$. As a typical example of such a case computed from actual values of a practical case, curve C in Fig. 14 is given. This is for an object in which the brightness range is from 15 ml. to 1000 ml., while the intensity of the illumination on the positive during observation is such that the brightness range is from .35 ml. to 10 ml.

Fig. 14, therefore, represents the complete general graphic solution giving the reproduction curve D, which is a graphic representation of the reproduction of the subjective impression obtainable under any set of specified conditions, the line E being the curve of exact reproduction of subjective contrast. It should be noted that with the particular values assumed in this case, the reproduction curve D is somewhat straighter in the highlight region than when a straight line was used as the relative subjective contrast function. It is probable in practice that the change in adaptation level is not so great as is indicated by the assumptions made in this case, and that the improvement in contrast reproduction is not so great as indicated by the curve shown.

Many interesting relations between the various factors may be derived and applied to practical problems, but the discussion of

such details will not be taken up at this time. One point deserving mention at this time, however, is relative to the values of adaptation of the eye, upon which depend the sensibility values from which the slope of the subjective relative-contrast function is computed. Few data are at present available as to adaptation levels when the visual field is filled by areas of different bright-

FIG. 14.
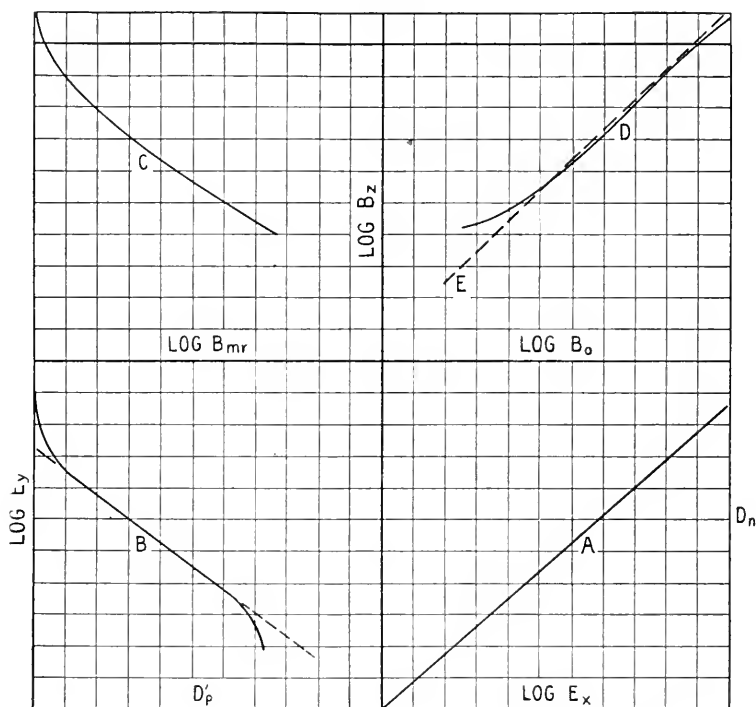
A general case of the complete solution including the subjective phase.

nesses, such as exists under practical conditions. Experimental work is at present in progress in this laboratory, from the results of which it is hoped more reliable evaluations of A_o and A_{mr} may be obtained for certain specified practical conditions. When these data are available, it will be possible by the application of the general principles outlined in this paper to arrive at more certain conclusion, relative to the exactness of reproduction in any particular case.

PRESENTATION OF THE FRANKLIN MEDAL.
MAY 19, 1920.

At the Stated Meeting of the Committee on Science and the Arts held March 3, 1920, the following resolutions were adopted:

"*Resolved* That The Franklin Medal be awarded to Sir Charles Algernon Parsons, of England, in recognition of his epoch-making success in the development and construction of the steam turbine, which has revolutionized the art of steam engineering, particularly in regard to the propulsion of mercantile and naval vessels, and the driving of electrical generators."

"*Resolved*, That The Franklin Medal be awarded to Professor Svante August Arrhenius, of Sweden, in recognition of his notable contributions to the theory of physical science, which have found unprecedentedly extended and fruitful application in the experimental study of chemical, physical, biological and cosmic phenomena, as well as in industrial chemistry."

CORRESPONDENCE WITH MEDALISTS.

THE FRANKLIN INSTITUTE
OF THE STATE OF PENNSYLVANIA
Philadelphia

OFFICE OF THE SECRETARY   MARCH 26, 1920.

Sir Charles Algernon Parsons, K.C.B., C.B., M.A., LL.D., D.Sc., F.R.S.,
  6, Windsor Terrace,
    Newcastle-on-Tyne,
      England.

SIR:

I have the honour to inform you that The Franklin Institute has awarded you The Franklin Medal, founded for the recognition of those workers in physical science or technology, without regard to country, whose efforts in the opinion of the Institute have done most to advance a knowledge of physical science or its applications. The award is minuted as follows:

"That The Franklin Medal be awarded to Sir Charles Algernon Parsons, of England, in recognition of his epoch-making success in the development and construction of the steam turbine, which has revolutionized the art of steam engineering, particularly in regard to the propulsion of mercantile and naval vessels, and the driving of electrical generators."

The medal and accompanying certificate are being prepared, and Sir Auckland Geddes, your Government's Ambassador at Washington, is

Charles A. Parsons.

being requested to come to the Institute on the afternoon of Wednesday, May 19th, to receive this medal and certificate on behalf of his Government, for you.   I am,

Respectfully,

(Signed) R. B. OWENS,

RBO : S   *Secretary.*

THE FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA

Philadelphia

OFFICE OF THE SECRETARY   MARCH 26, 1920.

Professor Svante August Arrhenius, Ph.D., M.D., D.Sc., LL.D.,

Director, Physico-Chemical Department,

Nobel Institute,

Stockholm, Sweden.

SIR :

I have the honour to inform you that The Franklin Institute has awarded you The Franklin Medal, founded for the recognition of those workers in physical science or technology, without regard to country, whose efforts in the opinion of the Institute have done most to advance a knowledge of physical science or its applications.   The award is minuted as follows:

"That The Franklin Medal be awarded to Professor Svante August Arrhenius, of Sweden, in recognition of his notable contributions to the theory of physical science, which have found unprecedentedly extended and fruitful application in the experimental study of chemical, physical, biological and cosmic phenomena, as well as in industrial chemistry."

The medal and accompanying certificate are being prepared, and Mr. W. A. F. Ekengren, your Government's Minister at Washington, has been requested to come to the Institute on the afternoon of Wednesday, May 19th, to receive this medal and certificate on behalf of his Government, for you.   I am,

Respectfully,

(Signed) R. B. OWENS,

RBO : C   *Secretary.*

THE FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA

Philadelphia

OFFICE OF THE SECRETARY   APRIL 1, 1920.

Sir Auckland Geddes, Ambassador Extraordinary,

and Plenipotentiary of His Britannic Majesty,

British Embassy,

Washington, D. C.

YOUR EXCELLENCY :

I have the honour to inform you that The Franklin Institute has awarded to Sir Charles Algernon Parsons, of Newcastle-on-Tyne, Eng-

Svante Arrhenius
Sept. 1918.

land, The Franklin Medal, founded for the " recognition of those workers
in physical science or technology, without regard to country, whose efforts
in the opinion of the Institute have done most to advance a knowledge of
physical science or its applications." The award is minuted as follows:

> " That The Franklin Medal be awarded to Sir Charles Alger-
> non Parsons, of England. in recognition of his epoch-making suc-
> cess in the development and construction of the steam turbine,
> which has revolutionized the art of steam engineering, particu-
> larly in regard to the propulsion of mercantile and naval vessels,
> and the driving of electrical generators."

The medal and accompanying certificate are being prepared, and I
am requested, on behalf of our management, to extend to you a cordial
invitation to come to the Institute on the afternoon of Wednesday,
May 19th, to receive this medal and certificate from our President, on
behalf of your Government, for Sir Charles.

A second medal has been awarded to Professor Svante August
Arrhenius, of the Nobel Institute, Sweden, in recognition of his notable
contributions to physical science.

You and Mr. W. A. F. Ekengren, Swedish Minister at Washington,
will be asked to be guests of honour at a dinner to be given on the same
evening, but in this connection our President, Dr. Walton Clark, will
communicate further with you.

<div align="center">I am,</div>

<div align="center">Your Excellency's very humble servant,</div>

<div align="right">(Signed) R. B. Owens,</div>

RBO : C   *Secretary.*

<div align="center">THE FRANKLIN INSTITUTE</div>

<div align="center">OF THE STATE OF PENNSYLVANIA</div>

<div align="center">Philadelphia</div>

OFFICE OF THE SECRETARY   APRIL 1, 1920.

W. A. F. Ekengren, Esq.,
  Envoy Extraordinary and Minister Plenipotentiary,
    of His Swedish Majesty,
      Swedish Legation,
        Washington, D. C.

SIR:

I have the honour to inform you that The Franklin Institute has
awarded to Professor Svante August Arrhenius, of the Nobel Institute,
Stockholm, The Franklin Medal, founded for the " recognition of those
workers in physical science or technology, without regard to country,
whose efforts in the opinion of the Institute have done most to advance
a knowledge of physical science or its applications." The award is
minuted as follows:

> " That The Franklin Medal be awarded to Professor Svante
> August Arrhenius, in recognition of his notable contributions to
> the theory of physical science, which have found unprecedentedly

extended and fruitful application in the experimental study of chemical, physical, biological and cosmic phenomena, as well as in industrial chemistry."

The medal and accompanying certificate are being prepared, and I am requested, on behalf of our management, to extend to you a cordial invitation to come to the Institute on the afternoon of Wednesday, May 19th, to receive this medal and certificate from our President, on behalf of your Government, for Professor Arrhenius.

A second medal has been awarded to Sir Charles Algernon Parsons, of Newcastle-on-Tyne, England, in recognition of his epoch-making success in the development and construction of the steam turbine.

You and Sir Auckland Geddes, British Ambassador at Washington, will be asked to be guests of honour at a dinner to be given on the same evening, but in this connection our President, Dr. Walton Clark, will communicate further with you.

<div style="text-align:center">I am,</div>

<div style="text-align:center">Respectfully,</div>

<div style="text-align:center">(Signed)   R. B. OWENS,</div>

RBO:S   *Secretary.*

<div style="text-align:center">LEGATION OF SWEDEN
Washington, D. C.</div>

<div style="text-align:right">APRIL 6, 1920.</div>

Mr. R. B. Owens, Sec'y.,
   Franklin Institute,
      Philadelphia, Penna.

SIR:

I have the honor to acknowledge, with best thanks, the receipt of your kind letter of the 1st inst., inviting me to come to The Franklin Institute in the afternoon of Wednesday, May 19th, to receive on behalf of my Government the Franklin Medal which has been awarded to Professor Svante August Arrhenius of Stockholm.

In reply, I would state that I shall come with much pleasure.

<div style="text-align:center">Cordially yours,</div>

<div style="text-align:center">(Signed) EKENGREN,</div>

LH:GH   *Minister of Sweden.*

<div style="text-align:center">NOBEL INSTITUTE
EXPERIMENTALFALTET
Sweden</div>

<div style="text-align:right">APRIL 19, 1920.</div>

DEAR DOCTOR OWENS:

It was an extraordinarily great honor and pleasure to receive your two letters of March 26th which I received on April 14th. The mail is very slow nowadays. If it takes the same time back, you will, I hope, have this answer after 18 days, *i.e.,* on May 6th, in due time before the meeting on May 19th.

In order that you should have this letter as soon as possible and surely before the 19th of May, I have had to write my biographical sketch (with my last photo) and a small paper rather rapidly. I, therefore, suppose that some errors or unusual phrases have crept into the writings. I would, therefore, be extremely glad, if you would kindly let some one in America look through them for making the necessary corrections.

I hope also that the printer will be able to read the manuscript, although it is not typewritten, but I think it will be necessary to read the proofs rather carefully.

I would be glad to receive some copies, *e.g.*, 25, of this small paper.

The content of it has interested me for a very long time, as is easily seen from my book " Worlds in the Making," Chap. 2. I think that it will be necessary to make an international law against the wasting of natural treasures, which are not constantly reproduced by Nature, through solar radiation. It will also be necessary to ration coal and also some ores in order that countries which do not possess deposits of these necessities, shall not become poor and starve. For coal is now as necessary as bread and we in Europe suffer very much from the bad situation, regarding coal and also iron ores, which is due to the dictates in the peace treaty and which prevents the economical restoration of Europe.

I think that these questions are the most important for humanity and that it is of the greatest consequence that they draw the attention of industrials and statesmen.

I would be very.thankful if you were so kind as to say my most respectful thanks to the members of The Franklin Institute for the highly appreciated honor which they have bestowed upon me.

<div align="center">

Believe me to be,

Yours faithfully,

(Signed) SVANTE ARRHENIUS.

</div>

<div align="center">

BRITISH EMBASSY

Washington

APRIL 24, 1920.

</div>

DEAR MR. OWENS:

It will give me great pleasure to come to Philadelphia on May 19th to receive on behalf of my Government the Franklin Medal awarded by your Institute to Sir Charles Algernon Parsons. It is particularly gratifying to myself, as a student of science, that my first visit to your city should take place under circumstances which emphasize the friendly coöperation of the two great English-speaking races in the advancement of scientific knowledge.

<div align="center">

Very truly yours,

(Signed) A. GEDDES.

</div>

R. B. Owens, Esq.,
   Secretary, The Franklin Institute,
      Philadelphia,
         Pennsylvania.

1, Upper Brook St.,
W. I.,
27 April.

Dear Professor Owens:

I have been anxiously considering how to meet your kind wishes in regard to a paper for your May Meeting in the allotted time, and besides I have not been very well or energetic.

As you say, the subject "Notable War Inventions" has been more or less covered in my B. A. address and "The Steam Engine and Industrial Progress" in another of my publications.

A paper dealing with "The Steam Turbine of Today" would take some time to prepare.

I, therefore, came to the conclusion that though perhaps unusual, just a few reminiscences of the early days of turbine development, which would occupy but a few minutes, might be appropriate and to some extent new.

I have pleasure in sending you the only good report of my lecture this spring at the Royal Institute on "High Temperatures and Pressure," also copy of my paper on "Diamond Researches" and copies of my B. A. address.

I must again express my deep appreciation of the honor of The Franklin Medal.

I am looking forward when things have settled down here of paying another visit to America. I well remember with the greatest pleasure my visit to Philadelphia in 1884.

<div style="text-align:center">

With very kind regards,
I am,
Yours very sincerely,
(Signed) Charles A. Parsons.

</div>

<div style="text-align:center">

Telegram from His Excellency, Mr. Ekengren, to Dr. R. B. Owens, Secretary, Dated May 17, 1920.

</div>

Have been quite seriously ill for some time, but however have right along had every reason to believe that I should be well enough to come to Philadelphia, Wednesday, to receive, on behalf of the Swedish Government, the medal with which your Institute has honored my illustrious countryman, Dr. Arrhenius. I was discharged from the hospital about a week ago, and in my opinion have been progressing normally, but to my consternation my physician tells me today that he will under no circumstances permit me to take the trip. If I had only myself to consider I should, I assure you, be greatly inclined to disobey my Doctor's orders and come to Philadelphia, as I have promised, but as it is I must consider the position here that my Government has entrusted me with, as I must also consider my family.

Under the circumstances I must therefore refrain from disregarding my Doctor's orders.

Mr. Joen De Lagerberg, who is the Legation's Secretary, will consequently represent me. He will be accompanied by our Vice Consul in Philadelphia, Mr. Eric Brolin. Mr. Lagerberg will arrive in Philadelphia tomorrow afternoon, and will attempt to communicate with you then.

I assure you my unfortunate disability distresses me more than I can convey to you.

EKENGREN,
Swedish Minister.

PROGRAMME OF MEETING, MAY 19, 1920.

Presentation of The Franklin Medal to His Excellency, Sir Auckland Geddes, British Ambassador, on behalf of His Britannic Majesty's Government, for the Honourable Sir Charles A. Parsons, Newcastle-on-Tyne, England.

Presentation of The Franklin Medal to His Excellency, Mr. W. A. F. Ekengren, Minister of Sweden, on behalf of His Swedish Majesty's Government, for Professor Svante August Arrhenius, Nobel Institute, Stockholm, Sweden.

Papers:

"Some Reminiscences of Early Days of Turbine Development." Sir Charles A. Parsons, K.C.B., C.B., M.A., LL.D., D.Sc., F.R.S. Read by Mr. Charles Day, Vice-President, The Franklin Institute, Philadelphia. "The Problem of the World's Supply of Energy." Professor Svante August Arrhenius, Ph.D., M.D., D.Sc., LL.D. Read by Allerton S. Cushman, Ph.D., Director, The Institute of Industrial Research, Washington, D. C.

PRESENTATION OF THE FRANKLIN MEDAL TO SIR CHARLES A. PARSONS AND PROFESSOR SVANTE AUGUST ARRHENIUS.

IN calling the meeting to order the President of the Institute announced that the business of the meeting would be the annual presentation of the Institute's highest award, The Franklin Medal, in recognition of distinguished scientific and technical achievement, and recognized Dr. Harry F. Keller, who made the following statement relative to the work of Sir Charles A. Parsons:

Mr. President: For the first time since The Franklin Medal was founded in 1914, both impressions of it are awarded to foreign scientists. On a previous occasion, in 1915, the two medals went to Americans, but as a rule one of the medalists was a foreigner and the other a compatriot of ours. In every instance, however, the Committee on Science and the Arts, in its recommendations for this award, has endeavored scrupulously to carry out the

provisions in the deed of gift that the recipients " without regard to country " be those " whose efforts, in the opinion of the Institute, have done most to advance physical science or its applications." On the present occasion our medalists could hardly be expected personally to receive from you this highest award in the gift of the Institute; but we are honored by the presence in our midst of official representatives of their Governments in this country who have graciously consented to accept, on behalf of their Governments, The Franklin Medals for their fellow-countrymen.

The first of these medals is awarded to the Honorable Sir Charles Algernon Parsons, K.C.B., of Newcastle-upon-Tyne, England. It is given to him as a tribute to his inventive genius, and in recognition, particularly, of his marvellous work on the steam turbine.

Sir Charles was born June 13, 1854, as the fourth son of the third Earl of Rosse, who was a President of the Royal Society, and built that famous telescope which is still the largest instrument of its kind.

The son received his early education entirely by private tuition, and later attended Dublin University and Cambridge, taking high honors as Eleventh Wrangler in the latter place. At that time (about 1877) he made models of his epicycloidal engine, and while serving a four years' apprenticeship in the Elswick Works he constructed the first engine of this type. It was a four-cylinder revolving engine in which the cylinders rotated around the revolving crank shaft. A large number of these engines were manufactured during the following two years.

Mr. Parsons then turned his attention to the development of the steam turbine. He conceived the idea of splitting up the fall in pressure over a great number of turbines in series, in order that the aggregate of these simple turbines, constituting a complete machine, would give an efficiency approximating that of water turbines. The great mechanical difficulties of producing such a machine were overcome by his indefatigable efforts.

In 1884 Mr. Parsons patented his first steam turbine. The first one he built was of 10 H.P., with 18,000 R.P.M., and was used for driving a high-speed dynamo. It marked the beginning of turbo-generator development for electric drive.

During the next five years he constructed many improved

forms of turbo-dynamos, and some 300 of these ranging in capacity up to 75 Kilowatts were turned out by the firm of which he was the junior partner. In 1889 he organized the works at Heaton, Newcastle-on-Tyne, and abandoning the parallel-flow system, began to experiment with turbines of the radial-flow type. In the paper prepared by Sir Charles, and to be read by Mr Day, the story of how there was tested every previous turbine invention, and many others since claimed as new, will doubtless be told us.

The first compound turbine was built in 1887, and the first condensing turbine in 1892, when there was at once a great advance in efficiency, the steam consumption being reduced from 55 lbs. to 27 lbs. per Kilowatt hour.

In 1895 the steam turbine was first applied to marine work, and two years later the experimental steamer *Turbinia,* driven entirely by turbines, was completed. She had a length of 100 feet, 9-foot beam, and 44 tons' displacement. The speed attained on her trial trip was 34 knots. During the following years larger vessels for which Parsons' Works at Wallsend supplied the turbines were built, each showing marked improvements over the preceding ones. In 1905 the *Amethyst*, equipped with turbines, beat her sister ship, the *Topaz*, which was driven by reciprocating engines. From this time on the construction of turbine-driven vessels advanced by leaps and bounds, until the present time, when the turbine has not only completely supplanted the reciprocating engine in war vessels, but to a great extent also, either wholly or partly, in the great ocean liners and mercantile steamers. It is to the constructive genius of Sir Charles Parsons that we owe the combination of reciprocating engines and steam turbines in many instances. By connecting the turbines to the propeller by gearing he has made possible another great stride in turbine propulsion.

The pioneer work of Sir Charles Parsons has brought about a revolution in the steam-driven machinery on land, as it has in that of ships. The central power plant of the present day would indeed be impossible without the steam turbine. It has been the means of producing steam-driven units up to 70,000 K.W., which are operated with only a fraction over ten pounds of steam per K.W. hour. While it is true that the development of the modern steam turbine is not to be credited to Parsons only, and that other great engineers have contributed their share to

it, it was he who first recognized the possibilities of the steam turbine, and the first to construct a practical machine. Nor should it be forgotten that since he first entered the field more than thirty years ago, he has been continuously active in the development and production of the new type of prime mover.

Sir Charles Parsons has made valuable contributions and inventions along other lines in physical science. Among them may be mentioned improvements in gramophones and investigations on the formation of diamonds. He must also be credited for the very active interest he has taken in technical education.

He is a Fellow of the Royal Society and has served as a member of its Council. His achievements have been recognized by honors and distinctions of all kinds, including honorary membership and medals from the leading engineering societies of various countries, degrees from great universities, the Freedom of the City of Newcastle-on-Tyne, and the Order of K.C.B., conferred upon him by His Majesty the King, in 1911.

The Franklin Medal awarded to him by The Franklin Institute, Mr. President, will now be accepted on behalf of His Majesty's Government, for Sir Charles, by His Excellency, Sir Auckland Geddes, the British Ambassador, whom I have the honor to present to you.

The President, in presenting The Franklin Medal to Sir Auckland Geddes, said:

Your Excellency, the members of The Franklin Institute are appreciative of the distinction conferred upon their meeting by the presence of a representative of the Government of Great Britain, and the Board of Managers of The Franklin Institute have commissioned and instructed me to convey to you the assurances of their high personal regard and their gratitude that you have come to take a part in our simple ceremony.

Your Excellency, I have the honor, in the name of The Franklin Institute, upon the recommendation of its Committee on Science and the Arts, to present to you, for transmission through the State Department of your Gracious Sovereign, to Sir Charles A. Parsons, the Franklin Medal and Diploma and a Certificate of Honorary Membership in The Franklin Institute.

The award to Sir Charles of this medal and these documents is in recognition of his distinguished services to mankind ren-

dered in the field of science.   It is the highest honor in the gift of The Franklin Institute.

Sir Auckland Geddes in accepting The Franklin Medal on behalf of his Government for Sir Charles A. Parsons, said:

Mr. Chairman and Gentlemen: I regard it as a great honor to be privileged to receive at your hands the Medal which you have awarded to my distinguished fellow-countryman, the Honorable Sir Charles Algernon Parsons, K.C.B.

By your award of this medal you have shown clearly that you need no urging by me to appreciate what Sir Charles's invention of the steam turbine has meant and means to the naval architect, to the naval forces and mercantile marine of all nations as well as to those who are interested in supplying or receiving electric power as cheaply and economically as possible.   By the same action you have shown something more with equal clarity. You have shown that your outlook is not limited by national frontiers, but that you can see across them in every direction and are willing, nay anxious, to recognize merit in the work of citizens of other lands.

Quite apart from the honor you have done Sir Charles Parsons, and in addition to it is the effect that such gracious acts of international courtesy have in sweetening international relations. I am no believer in what is called internationalism, but I do recognize that the many merits of national feeling are always liable to have some subtraction made from them on the ground that national patriotic enthusiasm is apt to be associated with an attitude of hostility towards, or perhaps more frequently, of contempt for other nations.   I remember that as a boy I was firmly convinced that one Scot, I am a Scot, could be relied upon to deal with two Englishmen.   I will not tell you how many men of other nations, according to my childish imaginings, it took to equal an Englishman, but I may say that a round dozen was not the limit.

These were extremely immature beliefs, but the common people of all lands cherish such beliefs to the end of their days, and when it came to war in 1914 it was no bad thing that the men of our contemptible little army were quite confident that they could take on four, five or more times their own strength in Germans and beat them.

In these days we have all had our fill of war, and we hope for peace in our time and in our children's time and in the time of our children's children. If we are to work to turn our hope into a reality, it is beyond question essential that we should continuously seek to see the good in nations other than our own, so that we approach all questions arising between ourselves and them not in a spirit of perhaps unconscious hostility or in a contemptuous frame of mind, but realizing that they, like ourselves, are contributors to the common stock of knowledge upon which, ethically and materially, the civilization of our day is founded.

It is, I think, no exaggeration to say that never has it been so necessary as it is to-day to seek to dispel the cloud of misrepresentation and misunderstanding which tends to separate the peoples of your country and of that which I have the honor to represent.

There are no misunderstandings that I know of, no lack of complete cordiality between the Governments of our two countries, yet many of your newspapers are filled with strange verbal pictures of what the British are, or are doing, which make me rub my eyes and wonder how, when, where such surprising stuff can be written. There are newspapers in England, only a few, thank God, that are filled with equally weird descriptions of your nation, its motives and its plans.

I am not speaking of criticism of action taken or not taken. There may be room for all sorts of criticism. That is a different story. I am speaking of wholly incorrect reports of simple facts and happenings.

To-day at this ceremony we have passed out of the Governmental into the popular sphere, and you have shown that you have no misunderstanding of the work and engineering triumphs of one of my distinguished fellow-countrymen. Behind all difficulties that ever have arisen between our nations, believe me there has always been one thing upon which you could count—there has been a rather formless but warm sentiment of desire for friendship associated with the word America in the average British mind. It will be all evil if that feeling is changed into one of less cordiality. Its existence is an asset to you and to us which you do well to foster. There can be no doubt that such ceremonies as this strengthen that sentiment and help it to acquire

some greater precision of form.   Therefore, I am not only proud and glad to come here this afternoon to accept this beautiful medal which you have awarded to Sir Charles Parsons, but also grateful that I have had the opportunity personally to thank you for what this gracious act of yours means to that cause which we, who care for the continuance of the civilization we have known, all must have so deeply at heart—the cause of removing mutual misunderstandings and mistrusts from the minds of the peoples of Britain and America.

Doctor Keller was again recognized and presented the following statement of the work of Professor Svante August Arrhenius:

Mr. President: In rising to discharge the pleasant duty of presenting to you the distinguished representative of the Swedish Government, who will receive from you the second Franklin Medal, for Professor Svante August Arrhenius, I must confess to feeling no little embarrassment as to how I might give an appropriate summary of the life work of this great physicist in the brief space of time allotted to me.   It seems an almost hopeless task upon which to venture.

The name of Svante Arrhenius is commonly associated with one of the greatest and most fruitful generalizations in the entire domain of chemistry—The Theory of Electrolytic Dissociation; but it is by no means this wonderful achievement alone that the Institute desires to recognize by the bestowal of its highest award upon the Swedish scientist, but rather the vast sum of constructive endeavor by which he has extended and illumined our knowledge of the physical universe.

Svante August Arrhenius was born at Castle Wijk, near Upsala, Sweden, February 19, 1859.   His father was the manager of the Wijk estate and also of the adjoining university properties.   His ancestors were farmers in Småland, Southern Sweden, where both of Svante's parents were born.   It was from the name of the old Småland homestead, Arena, meaning river bank, that the latinized family name, Arrhenius, was derived.

Shortly after Svante's birth the father removed to Upsala to assume entire charge of the university's extended estates, and it was in this ancient town that the boy received his early education.   In 1876 he was graduated from The Cathedral School, the youngest member of his class and near the head of it.   His

work in mathematics and the sciences was particularly brilliant.
After entering the university he made such rapid strides in his
studies that he succeeded in passing the examinations for the
degree of " candidate " at the end of the third semester. As
his major subject he chose chemistry under Cleve's direction, but
at the same time he zealously pursued mathematical studies, and
in 1881 he decided to become a physicist. Not satisfied with the
limited facilities of the Upsala laboratory, he went to Stockholm,
where he worked under Edlund's direction, acquiring in rapid
succession the degrees of " Licentiate" and of Doctor of Physics.
His first original investigation was on the subject of voltaic
polarization, and this was followed by " Researches on the Con-
ductivity of Electrolytes," which he presented as his dissertation
for the Doctorate, and which has since become a classic in the
annals of exact science. In the same year, 1884, he published
as a continuation to this paper the " Chemical Theory of Electro-
lytes." The two publications, though not entirely free from
doubtful or debatable opinions, are most remarkable for the
wealth of novel and fundamentally important ideas advanced in
them. Particularly striking at that time was the suggestion
that the affinity co-efficients of acids and bases should be propor-
tional to their electrical conductivities, a prediction which it was
impossible then to support by experimental data. But this Law of
Arrhenius was shortly afterwards verified by Ostwald at Riga.
In Sweden the results and views of Arrhenius were received
with scepticism, bordering on contempt, but fortunately their true
value was promptly recognized by leading scientists in other
countries and particularly by Ostwald. This helped to overcome
the prejudices of the Swedish chemists and physicists, and pres-
ently Arrhenius was permitted to " habilitate " himself as Dozent
at Upsala, and a little later he was granted an ample stipend by the
Swedish Academy, enabling him to make an extended tour to the
leading seats of physical research in various countries. While
at Leipzig, in 1887, he conceived the Theory of Electrolytic Dis-
sociation, his *magnum opus*, in which the main ideas of his former
publications are crystallized into one comprehensive and definite
generalization. The way for a favorable reception of this achieve-
ment had in the meantime been prepared by the researches of
Kohlrausch on the phenomena of electrolytic conduction, those of
van't Hoff on osmotic pressure, and by Raoult's work on the

depression of the freezing point of liquids by a substance dissolved in them.   All these, and others might be named that contributed materials for Arrhenius' theory.

The fertility of this Ionic Theory, as it came to be called, can hardly be overestimated; it is indeed without a parallel in physical science.   For more than a decade after its announcement it prompted and directed innumerable researches, in the course of which many well-known, but hitherto unexplained phenomena were quantitatively elucidated.   Among the subjects thus investigated may be mentioned the application of the theory to the law of mass action and its effect on the equilibria of the ions, culminating in the discovery of the law of dilution; a masterly study of the problem of chemical equilibrium of electrolytes; and also applications of the theory to such questions as the action of the voltaic pile, the analytical chemical reactions, the solubility of gases and many others.

It should be stated here also that soon after its publication Arrhenius' theory was successfully applied in the study and development of industrial, chemical and metallurgical processes. To it may be traced in a large measure the rapid progress that has been made during the past 25 years in many branches of applied chemistry, including some of the basic industries.

The signal success of Arrhenius as a pioneer in Physical Chemistry was recognized in his native country, as it had been abroad, and thus reacted favorably on his further career.   In 1895 he received a call to the Chair of Physics in the then newly founded University of Stockholm.   In this position he displayed such extraordinary ability as a leader and organizer, that the Faculty elected him Rector of the University in 1897.   He was repeatedly re-elected to this responsible post, but later declined re-election, as he felt that the duties of the office seriously interfered with his scientific pursuits.

In 1903 he was awarded the Nobel Prize in physics, and two years later he was appointed Director of the Physical Institute of the Nobel Foundation.   The laboratory building was erected according to his plans and under his direction.

Most of the papers on the Dissociation Theory were published by Arrhenius while he was working in foreign laboratories.   After his return to Sweden his research work took different directions, largely along lines of cosmic physics.   In

1905 he published a Treatise on Cosmic Physics in two volumes. In this remarkable work he embodied a series of investigations of which many were made by him and Ekholm jointly, while others were carried out by himself alone. They cover a wide range of subjects and reveal anew his astounding resourcefulness and originality. While not a few of the views here expressed are still discussed and contested, there can be no doubt that the discussion of such fundamental questions, as the origin and present state of sidereal bodies, has profoundly influenced and greatly stimulated the scientific thought of our time. The more popular book, " Worlds in the Making," published more recently, gives a fascinating summary of the subject, from Arrhenius' point of view. Among the many new conceptions introduced by Arrhenius into the study of cosmogony is that of the rôle he ascribes to the pressure of light in cosmic changes. He points out that the potency of this agent increases with the degree of division of matter, and thus becomes a most important factor in the phenomena of cosmic dust, nebulæ, the aurora, comets' tails, etc. His views on the origin and distribution of life are likewise interesting.

Another subject to which Arrhenius has made original and valuable contributions is that of serum therapy. It is to him that we owe the explanation of phenomena of the antitoxins discovered by Ehrlich, namely, that they are due to unstable compounds whose existence depends upon concentration equilibria, similar to those which govern weak acids and bases. The action of toxins and antitoxins thus becomes intelligible.

Mr. President, I realize that this brief sketch of Arrhenius' contributions to science touches only a few of the high lights of his achievements. It may suffice, however, to indicate that by stressing the great synthetic factors of science, this genius was enabled to open up new and fruitful avenues of research to chemistry, physics, meteorology, astronomy and medicine. We revere him as one of the foremost leaders of scientific thought of our time, and hosts of pupils and collaborators do homage to his inspiring leadership. He has wielded a powerful influence upon the scientific life of all countries, being preëminently an international scientist. His achievements are as familiar and as highly appreciated in America, England, France and Germany, as they are in his native land. His writings are addressed to the scientists

of all countries, and he has personally addressed the scientists of many countries, including our own, and generally in their own language.

I refrain from enumerating the many honors, distinctions and decorations that have been bestowed upon him. We rejoice that our beautiful Franklin Medal is now also to be conveyed to him, and that he has so appreciatively cabled his acknowledgment of the award.

I have the honor, Mr. President, to present to you Mr. Joen de Lagerberg, of the Swedish Legation, Washington, who on behalf of His Swedish Majesty's Government, will accept from you The Franklin Medal for Professor Svante August Arrhenius.

The President then said:

Mr. Lagerberg: The Franklin Institute is honored by the presence of a representative of the Swedish Government at this, one of its stated meetings, and I have been instructed by the Board of Managers of the Institute to assure you of their high respect for yourself and for the Swedish Minister, and of their gratitude that you have come to take a part in our ceremony.

Mr. Lagerberg, I have the honor, in the name of The Franklin Institute, upon the recommendation of its Committee on Science and the Arts, to present to you, for transmission through the State Department of your Gracious Sovereign, to Professor Svante August Arrhenius, the Franklin Medal and Diploma and the Certificate of Honorary Membership in The Franklin Institute.

This award is made to Professor Arrhenius in recognition of his distinguished services to mankind rendered in the field of science, and it is the highest honor in the gift of The Franklin Institute.

Mr. Joen de Lagerberg, Secretary of the Swedish Legation, in accepting The Franklin Medal on behalf of his Government for Professor Arrhenius, said:

Mr. President: Naturally it would have given my chief, the Swedish Minister, extraordinarily great satisfaction to have been able to act, at the festivities to-day, as interpreter of the feelings of pride and pleasure which fill all Swedes, in the Mother-country as well as on this side of the Atlantic, because of the honor which

has been bestowed on our great countryman, Professor Svante Arrhenius. It is self-evident that only a serious illness could have prevented him from heeding your amiable call and to have forced him to entrust to another the commission of accepting in the name of the Swedish Government, and on behalf of our illustrious countryman, your beautiful Franklin Medal—a distinction which to the whole world can only mean that Doctor Arrhenius is proclaimed one of the most eminent living scientists.

The work and scientific achievements of Doctor Arrhenius have already been set forth vividly and completely by Doctor Keller, and I shall not repeat them.

However, I could perhaps accentuate one of the features of my great countryman's character, a feature that is a very strong, if not the predominating characteristic of our race, the feature to which we owe that our name has been everlastingly inscribed in humanity's annals. I mean the desire for, even need of adventure, the longing to explore the unknown; in other words, the Viking instinct—Arrhenius is a Viking of thought, a chief among our Vikings of science.

The same love of adventure that prompted Rolf to set out for the coasts of Normandy; the same love of adventure that made Charles XII accomplish fable-like feats in warfare, and the same love of adventure that has prompted hundreds of thousands of our countrymen to come to this great land of the future, has prompted Arrhenius to explore and advance, and advance and explore in the unlimited land of the Universe.

Nothing could more vividly explain what I try to say than the epical titles of his works:

> " Worlds in the Making."
> " Life of the Universe."
> " The Destinies of the Stars."

If in this connection I might be permitted to speak in my own name it would be only to mention how gratefully I remember the opportunities I had as a school-boy to listen to his wonderful lectures. Through him my generation, and generations to come, learned that science is more wonderful than any fiction, and that the very gates of the magic land of imagination, which, for instance, Wells pictures in his most daring works, sooner or later open at the pronunciation of " Open Sesame " by science.

There is something symbolic in the fact that the land which has so irresistibly drawn toward it, yes, to it, the Viking spirit

of so many of Sweden's sons, the land which itself among the peoples of the world represents the youthful striving toward the adventure of the future, has laurel-crowned this bold traveller in the future-land of science.

May this beautiful token of honor, The Franklin Medal, be another seal of the warm friendship that has always bound our two countries together and which friendship grows stronger each day in the measure that human cultivation, so eminently represented by The Franklin Institute, tears down the barriers which time and space have placed between us.

Mr. Charles Day, Vice-President of the Institute, then read the following paper prepared by Sir Charles A. Parsons:

SOME REMINISCENCES OF EARLY DAYS OF TURBINE DEVELOPMENT.

BY

SIR CHARLES A. PARSONS, K.C.B., C.B., M.A., LL.D., D.Sc., F.R.S.

ON previous occasions it has, I believe, been sometimes customary for the recipient of the honor of The Franklin Medal to give some account of his past history, and I will, therefore, now endeavor to give a few reminiscences which may be of some interest. I was educated on what is called among engineers the sandwich system. My father had a rooted objection to public school education, and consequently, with my brothers, I was taught by tutors at our home in Ireland. Concurrently I had the advantage of working in well-equipped workshops where my father had constructed his telescopes, and from him I learnt the first principles of mechanics and engineering, for he was a skilled engineer as well as a scientist and an astronomer. After that were interposed five years of pure and applied mathematics, including the Cambridge Tripos; and I recall that the strain was more severe than I have subsequently experienced in business life, and luckily for me, boat racing interfered with reading. In 1876 I entered Sir William Armstrong's Elswick Works as a premium apprentice, and served three years; during this time I learned from Sir William Armstrong and his staff the methods of mechanical research and construction that have made the works famous throughout the world, as the introducers of hydraulic machinery and subsequently also as constructors of guns and warships, methods closely analogous to those which the

workers in Physical Science have followed from the time of Faraday, methods which have resulted in the enormous developments in Science that have taken place in modern times. In those days I was immensely impressed by Sir William Armstrong's mechanical genius, the layout of his experiments, and his judicial selection of the fittest, and perhaps above all, by his extraordinary attention to minute details in critical cases of difficulty, while ordinary general administration he deputed to others. When he was busy with a difficult problem he concentrated his attention on it alone, and his powers of mechanical diagnosis were truly remarkable. When I recall these facts, and that he excelled Whitworth in the battle of the guns, I picture him as the cleverest mechanical engineer I have ever known. In later years, in my own business, I have endeavored to follow the same methods and principles, and have made many more failures than successes (numerically speaking) in the effort to progress as my tecahers had done before me, yet the failures should and have been soon discerned and force concentrated on the successes. When I commenced to work on the steam turbine in 1884, with the hope of making it a practical success, it seemed to me, in spite of the fact that many had previously failed in their endeavors, that it was right in principle, and that after a thorough experimental investigation it should be possible to realize success. In short, I thought it was worth trying; encouraging results followed; one improvement led to another, and it gradually became an efficient motor. When it had beaten a compound engine at driving a dynamo, my old friend, Doctor John Bell Simpson, said to me one day, when we were out shooting, " Why not try it at driving a ship? " to which I replied that I thought the time was ripe for the attempt. This was the beginning of the marine turbine in 1893, and of a strenuous time. First of all, the experimental stage was successfully completed by 1897, sufficient capital having been provided at the start; and here incidentally I recall with gratitude the kindness of the Tyne Commissioners, who did not prohibit the *Turbinia* from making trials at 30 knots in the Tyne, whereas the speed limit was 7 knots, which saved months, for many trials were run in storms and snow, when it was impossible to run so small a vessel at high speed in the open sea. Then followed the uphill attack on the market, followed by the total loss of the torpedo-boat destroyers *Viper* and *Cobra*, the latter involving the loss of many valuable lives. This was concurrent with the time of

maximum financial stress, because both vessels had cost more than their price, but the work, in spite of this, was steadily pursued. At this juncture, the munificence of Mr. Christopher John Leyland was of inestimable help. From the commencement he had been a director. His love of work and great interest in the marine development led him to attend almost every trial trip. On the *Turbinia* I was Chief Engineer and he was Captain, a position to which his naval services entitled him, and apart from the financial side his help was great. The late Sir William White did much towards the introduction of turbines into the British Navy, and while he was Naval Constructor at the Admiralty the order for the first turbine-driven destroyer, *Viper,* was placed, and the first turbine-driven cruiser, *Amethyst,* was requisitioned. Sir Philip Watts also strongly advocated the turbine when he was at Elswick, and afterwards when Chief Constructor at the Admiralty; but the general introduction of the turbine in the Navy soon afterwards was primarily due to the success of the *Amethyst* and to the enterprise of the British Admiralty themselves, who, in this field, as well as in others, have been pioneers among the nations. My old friend, Sir Archibald Denny, was one of the first to recognize the advantage of the turbine for cross-channel steamers, and induced his firm to join with Captain John Williamson and our Company to build and start the first mercantile turbine steamers on the Clyde. But from this brief account I must not omit to mention one other name, that of my old friend, Dr. William Garnett, who, when Principal of the Durham College of Science in Newcastle, took a great interest in turbines, and who was chiefly instrumental in inducing the authorities to use turbines exclusively for the lighting of the Newcastle Exhibition of 1887; and, lastly, I should mention that the great factor for success, as is necessarily the case, has been the enterprise, hard work, skill and loyal coöperation of the directors and staffs of our land and marine works, and that in my colleagues I have been extremely fortunate. Though we have had some trying times, work has almost always been a pleasure, and I feel that I owe more to them than I can well express. In closing, allow me again to say how deeply I appreciate the great honor you have conferred by awarding to me The Franklin Medal.

Dr. Allerton S. Cushman then read the following paper for Professor Arrhenius:

THE PROBLEM OF THE WORLD'S SUPPLY
OF ENERGY.

BY

SVANTE AUGUST ARRHENIUS, Ph.D., M.D., D.Sc., LL.D.

Since the days of Watt the physical well-being of mankind has become more and more dependent on fossil fuels. The life of to-day would be impossible without the enormous supply of coal necessary to industrial establishments, for railways and steamships, in the metallurgical arts and for the heating and lighting of our houses. The demand for fossil coal has increased very rapidly, about doubling every ten years during the last century, and is now some 1200 millions of metric tons per year. It is clear to those who have studied the matter that our coal fields will be exhausted after a certain time. When this calamity will happen, and the probability of the discovery of substitute sources of energy, are questions of vital importance.

One of these questions was answered by the Geological Congress in Canada in 1913. The quantity of fossil coal down to a depth of 1800 metres would suffice for 6000 years, at the present rate of consumption, if it were all recoverable, but a very great deal of this coal occurs in beds too thin for profitable working, a considerable part is lost as dust, or left in the mines as pillars, and further, the use of coal will probably increase in the future just as it has done in the past. It is, therefore, necessary to reduce the indicated time considerably, probably to one-fourth, or about 1500 years.

Of the different countries the United States, in the matter of coal, has the best position, as it has in the matter of other natural resources. The coal treasures there will probably suffice for about two thousand years. The worst situation among the great coal-producing countries is that of England, where the coals will be exhausted within a little less than two hundred years. Germany will be able to meet its demands during a little more than a thousand years.

This time of some few hundreds or thousands of years is very short compared with the time estimate made at the Geological Congress referred to, and only about one per cent. of the period of man's existence, which probably lies between the thousandth and ten-thousandth part of the time during which life

has existed on our earth. It is quite clear that we must soon ration our coal, and substitute as far as possible for fossil fuel other sources of energy.

It is often suggested that we might use mineral oils as fuel instead of coals. This advice rather reminds one of the words of Marie Antoinette: " If the people complain that they have no bread to eat, why do they not eat cakes?" Petroleum is a far more valuable fuel than coal, because it is much easier to transport and to use effectively. The world's yearly production of mineral oils represents not quite three per cent. of the energy contained in the yearly production of coal. Petroleum ought, therefore, to be reserved for better purposes, *e.g.,* production of light and lubricants. Further, the recent failure of many oil fields indicates that we must economize this valuable material. According to David T. Day, U. S. Geological Survey, the production per well in the Appalachian oil field decreased from 207 barrels in 1861 to 1.73 barrels in 1907. The production of West Virginia had, in 1910, declined 56 per cent. from its maximum output. The oil obtained from the New York and Pennsylvania oil fields fell to 50 per cent. from the year 1891 to 1898. If we suppose the present fields of the United States and the present rate of exploitation should continue, petroleum would be exhausted by about 1935, and if the present production goes on with no increase, the product would be exhausted in about ninety years, said Charles R. van Hise in 1910, who has done so much to warn against waste in the expenditure of our natural resources. The output of mineral oil has been kept up through an enormous increase in the number of oil wells in each field, and by opening up new fields, *e.g.,* in Oklahoma and California. There are very rich new oil fields in the world which are still not used, or only in a small degree, *e.g.,* in Mexico and Mesopotamia and Turkestan, but certainly they will not last as long as the coal fields, even if the production of this fuel is restrained to but three per cent. of the simultaneous production of the latter.

Still much less is the hope that sources of natural gas may deliver more than a small fraction of the fuel value of the oil fields. Even peat, although an important fuel, can by no means compete with coal. Thus, for instance, in the United States the available peat is less than one-half of one per cent. of the estimated coal. Probably the relative value of the European peat

bogs is about the same as compared with the European coal fields. For heating purposes petroleum and peat cannot play an important rôle as compared with fossil coal.

It is very often said that for coal should be substituted the water power of our rivers, often called the " white coal." According to an estimate of Engler, the energy which might be economically taken out from these waterfalls amounts to about 60 per cent. of the energy of the present output of coal. But even this figure seems too high, for many of the waterfalls are located in rather inaccessible parts of the world, where no industry is likely to be developed for a long time. So it seems wise to reduce the figure of Engler about 50 per cent. If this is done, it is evident that there is little hope that white coal will be able to substitute for black, except in a small degree. For heating purposes water power will probably not be used in a noteworthy degree, because used directly for the production of mechanical or electrical energy it is at least three times as valuable as the equivalent quantity of heat. Further, the well-situated waterfalls are already developed in greatest part, at least, in Europe. Thus, for instance, in Switzerland nearly all the waterfalls which have a commercial value are developed, and in a little less degree the same is true in all the other industrial countries of Europe.

During the unhappy situation created by the world war, when there was a great scarcity of fuel, and even now, when fuel is extremely expensive, waterfalls were and rapidly are being put to use. Within a short time, therefore, this source of energy will be taken into the service of man, not sensibly diminishing the demand for coal. An estimate of the power of the waterfalls has been made by Koehn and by Keplan, and is of much interest. Although the figures are only approximate, I give them below, with some later corrections. The power is given in millions of horsepower and horsepower per inhabitant :

Country	Horsepower in Millions	Horsepower per Inhabitant
Asia	236	0.27
Africa	160	1.14
North America	160	1.17
South America	94	5.25
Europe	65	0.13
Australia	30	3.75
Total	745	Average 0.45

Country	Horsepower in Millions	Horsepower per Inhabitant
Canada	26	4
United States	100	1
Iceland	2	22
Norway	13	5.2
Sweden	6.7	1.2
Finland	2.6	0.8
Balkan Countries	10	0.6
Switzerland	1.5	0.4
Spain	5.2	0.26
Italy	5.5	0.15
France	6.0	0.15
Austria-Hungary	6.2	0.12
Germany	1.43	0.02
Great Britain	1.0	0.02
Russia	3.0	0.02

These figures are not altogether reliable. Thus, for instance, Leighton gives for the United States 200 millions, and van Hise says: "Others regard this estimate as too high, and say 100 million horsepower is nearer to truth." I think this latter figure is more to be depended on. Van Hise is of the opinion that even it will meet the needs of a population of 250,000,000. Since his estimate made in 1910 the demands for power have greatly increased, and probably only about one-half of the energy given in the table above is available at present without excessive initial expenditures. We may, therefore, assume 0.5 horsepower per inhabitant as adequate to present needs. We find then that Europe and Asia are the only parts of the world where water power is really scanty—in Asia the demand is still so small that even this power per inhabitant is more than sufficient. Especially fortunate are those countries, such as South American Republics, and Australia, where water power per unit of population is well beyond this figure, and may be developed at a moderate cost. The United States is among the great powers very well endowed in this regard, as in most other natural sources of wealth, such as metal, ores and coal. In Europe, Iceland ranks first, because of its small population, and the old Saga Island may yet know a new and flourishing era. Then come the Scandinavian countries, the first being Norway, which has already greatly profited through its cheap power, and is destined to be one of the leading industrial countries of the future. Sweden and Finland possess enough power for their needs. Their waterfalls are not high, and in

general are far from established lines of communication, especially from those of the ocean. Denmark has scarcely any water power, as also Holland. Among the other countries of Europe the Balkan States have more power than their industrial needs require. Switzerland may also be regarded as having a nearly sufficient supply of water power, which is the more fortunate, as this highly industrial country does not own any coal deposits. The same is true of the new Austria, which has lost its old coal districts but has retained by far the greater part of the waterfalls of the old Austria, so that it now probably ranks with Switzerland in this respect. Spain is also a relatively well situated state, but which up to the present has not made much use of its resources. In general, the waterfalls in the Alps, Spain, Italy and the Balkans are high and of great value. For the industries of France and Italy water power is of the greatest importance, although it must be regarded as insufficient for nations so highly developed. At the end of the list come the three great powers of Great Britain, Germany and Russia, with only a fiftieth horsepower per inhabitant. Russia is an agricultural country, with a very small demand for power, and agriculture will probably remain its chief industry because of its small power resources, both in coal and water. England and Germany, now the most highly developed industrial countries in the world, will undoubtedly also, in the future have agriculture for their chief industry. Probably a great part of these countries will again be covered by forests, as they were in the time of Tacitus.

It is often asserted that the power of tidal waves should be utilized. Of course, this is possible, but doing so on a large scale would involve an initial investment not justified by prices likely ever to be obtained for power. The energy of the tidal wave is so widely distributed along the shores of the oceans that it is impossible to commercially collect a sensible part of it. It is quite in contrast to the energy of fossil fuel and waterfalls.

All available energy on the earth has its origin in solar radiation. Of this energy a small part, 0.12 per cent., is accumulated in vegetation, which, however, is great as compared with the energy of the coal burned in the industries. A detailed calculation, made by Professor Schroeder, of Kiel, shows that about twenty-two times as much energy is yearly accumulated in plants as is represented by the coal consumed in the same time. Of this energy

in vegetation 67 per cent. is taken up by the forests, 24 per cent. in cultivated plants, 7 per cent. in the grass of the steppes and 2 per cent. on desert lands. The energy collected by forests may be used for heating purposes, and exceeds every year that of the coals burnt by about fourteen times. But, unhappily, the greater part of this energy is collected in tropical areas, and the highly cultivated countries are so nearly deforested that their production of wood is not nearly sufficient as fuel for their industries. Further, the wood produced in civilized countries is needed for the production of paper, pulp and lumber. In forest lands the refuse from the woods may be sufficient for domestic purposes, and during the war even the industrial needs of certain countries for combustibles were met by wood, where the importation of coal was hindered by the blockade. The costs, however, were very high, due to the expensive transport from the forests to the industrial centres. The transport of wood from the immense forests in the tropics to industrial countries seems impossible on economic grounds. The forest lands possess, therefore, an advantageous position in this regard. Before other industrialized countries will be able to substitute wood for coal an economic solution of the transportation problem is necessary, which at present seems fraught with exceedingly great difficulties.

Two other sources of energy, greatly dispersed in form, remain to be considered, namely, those of the winds and of sunshine. They are extremely great, and exceed that of simultaneously burnt coal from 5000 to 70,000 times, respectively. The energy of the winds is taken up by windmills, which have been in use in Europe since the eleventh century. The great objection to wind as a source of power is its variability, and the high installation costs per unit of power continuously deliverable. It has been proposed to store the energy of the wind by means of accumulators, charged from windmills, and to use these accumulators during times of calm. But even in windy countries, *e.g.*, Denmark, this method is extremely uneconomical, as compared with coal or wood at their present price. Windmills are widely used for pumping water, both in the new and the old world.

The radiation of the sun may be concentrated by means of mirrors on a boiler, and this connected to a steam engine. The best known of these solar engines was constructed by John Ericsson, and described in *Nature* in 1888. It was an improve-

ment of an earlier machine constructed in 1860. In his experiments in New York, John Ericsson obtained an effect of one horsepower with a mirror of ten square metres' opening. Later, his experiments were taken up on a commercial scale by Mr. Shuman, of Philadelphia, who installed a solar engine, with mirror of 1200 square metres in all, at Meads, 10 kilometres south of Cairo, in Egypt. The machine was of the Ericsson type, with some small modifications, and auxiliary apparatus. Shuman did not obtain more than half the effect of that obtained by Ericsson, namely, one horsepower per twenty square metres mirror opening. After an inspection of Mr. Shuman's plant, Mr. Ackerman thought it possible to introduce improvements which would give as good results as those obtained by Ericsson.

After improvements the solar engine seems likely to play an important rôle in the opening up for cultivation of great arid districts in tropical countries, as Ericsson maintained with great energy it would do. In these parts of the world are great deserts, such as Sahara, the Arabian desert, the Syrian desert, and those in Mesopotamia, which have in historical times been the seat of flourishing culture, but are now the home of wandering tribes. The decay of these regions resulted from the destruction of their aqueducts and irrigation plants, which the present wandering population is unable to restore. With the aid of the solar machine it would be possible to re-establish the old agriculture and horticulture of these districts, and industrial works founded on its use might also be looked forward to. It is not only in the deserts that the sun is shining nearly continuously during the greatest part of the year, but extensive provinces in Spain, Greece and North America possess such a climate that they would profit by the introduction of the solar engine. In other parts of the world, where the sky is covered for the greatest part of the year, as in the Congo or the Amazonas, or which lie nearer to the poles, as the temperate regions, the solar machine will be of very little use.

It seems very probable that when fossil fuel has been consumed, civilization and culture will return to its birthplace about the Mediterranean and in Mesopotamia in the old world, and to Central America and the land of the Incas in the new.

According to some calculations made by me an increase of the carbonic acid in the atmosphere will give the whole earth a more uniform and warmer climate. Therefore, we may suppose

that the burning of coal will cause our climate to approach to that of the tertiary age. Furthermore, vegetation is highly stimulated through absorption of carbonic acid in the soil, augmented through an increase of the carbonic acid in the air. It is, therefore, probable, as I have tried to show in my book, "World's in the Making," that the total consumption of the available coal by the industries will, in a high degree, favor agriculture and the growing of forests in the temperate regions now the chief seat of culture. These regions will then know not only harmful, but some useful consequences as the result of the present waste of our fuel resources.

STOCKHOLM, NOBEL INSTITUTE, April 19th, 1920.

Light Scattering by Air and the Blue Color of the Sky. R. W. WOOD. (*Phil. Mag.*, April, 1920.)—The depth of a layer of air in full sunlight, with a black cave as a background, which would give a luminosity equal to 5 per cent. of that of the blue sky 600 from the sun on very clear days, was found to be 1000 ft. On slightly hazy days it was 400 ft. The air near the earth with its large load of dust has a scattering power 2.6 as great as the average scattering power of the entire atmosphere. When air carefully freed from dust is traversed by a beam of sunlight it is found that the quantity of light scattered at right angles to the beam is about equal to that scattered in the direction of the beam. If the entire thickness of the atmosphere were free of dust we should therefore expect to find no such great increase in brightness in the sky near the sun, as is observed under the present conditions. Modern experiments confirm Lord Rayleigh's attribution of the blue color of the sky to the effect of scattering by air molecules themselves without assistance from dust particles.

G. F. S.

The Great Potash Deposits of Germany. (*U. S. Geological Survey Press Bulletin, No. 443*, April, 1920.)—The potash deposits of Germany, which were discovered by the Prussian Government in 1843 at Stassfurt while boring for rock salt and which occur in upper layers of rock salt in the plains of northern Germany, have been estimated to occupy a volume of 10,790,000,000 cubic meters and to contain 20,000,000,000 metric tons of potash salts, corresponding to about 2,000,000,000 metric tons of potash (K_2O), a quantity sufficient to supply the world for two thousand years at the present rate of consumption. These beds, according to the United States Geological Survey, Department of the Interior, were first exploited about 1860, and have furnished practically the entire world's supply of potash for many years.

Casting and Treatment of Steel. J. H. ANDREWS. (*North-East Coast Institution of Engineers and Shipbuilders*, April 16, 1920.)—The paper deals with metallurgical research as applied to steel and with its uses and applications to engineers. The question as to what defines a good and a bad casting, and how each type can be obtained, is used as a basis and the following points are considered: High casting temperature and the effect of temperature upon skeleton crystalline structure; "chill" crystals, "dendrites," and "onion" crystals; Mr. Humphrey's method for distinguishing the high and low phosphorus parts of an ingot.

The author asserts that the only way in which to derive the most suitable treatment for any steel is to take a recalescence curve and carefully note the temperatures of the critical point or points. Actual heating curves of a number of steels are reproduced and discussed. The author's conclusions are that the mechanical properties of a steel depend primarily upon the degree of fineness of the structure; the means of obtaining this are summarized. The effect of manganese on the properties of steel is considered. The results of experimental impact tests upon a series of nickel steels are given.

The paper concludes with a few remarks upon the application of the microscope to metallurgical work.

Effect of Solution Reaction on Germination and Growth. (*Jour. Agric. Research*, 1920, vol. xix, 73.)—R. M. SALTER and T. C. McILVAINE, of the W. Va. Agric. Exp. Sta., report the results of many experiments very carefully made to determine the influence of hydrogen-ion and hydroxyl-ion concentration in soil-solution on the germination and growth of wheat, soybean, corn, red clover, and alfalfa. Some of their conclusions are:

Maximum growth of seedlings of wheat, soybeans, alfalfa, and red clover occurred in cultures having a hydrogen-ion concentration of 5.94 P_H, while corn showed the best results with a concentration of 5.16 P_H.

A reaction of 2.16 P_H was fatal to all seedlings in a short time and favored the growth of molds.

The hydroxyl-ion was apparently more harmful in equivalent concentration than the hydrogen-ion.

No indication of any harmful effect of a member of the monophosphate $(H_2PO_4)[1]$ other than that produced by the hydrogen-ion formed by its dissociation.

Germination of the seed was found to be less affected by an acid reaction than the subsequent growth of the seedling.

The optimum reaction for the germination of the five seeds studied is probably below 7.71 P_H and above 2.96 P_H, a slightly acid reaction being found favorable in all cases.

H. L.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

A NOTE ON STRESSES CAUSED BY COLD ROLLING.[1]

By H. M. Howe and E. C. Groesbeck.

[ABSTRACT.]

THE experimental data here presented show that a given amount of reduction by rolling causes less residual stress in the metal rolled if it is brought about by a large number of light drafts than if by a smaller number of heavy ones. This is shown by means of the curvature induced in each of a pair of superposed strips when they are simultaneously reduced in thickness by rolling, with varying reductions.

The result is attributed to the greater skin friction between the metal rolled and the face of the rolls with heavy than with light reductions. Because of this greater skin friction more of the reduction occurs through the backward forcing of the deeper-seated layers, and less through the elongation of the surface of the metal in contact with the rolls.

REFLECTING POWER OF MONEL METAL, STELLITE AND ZINC.[2]

By W. W. Coblentz.

[ABSTRACT.]

DATA are given on the reflecting power of monel metal, stellite and zinc in the visible and in the infra-red spectrum. The reflectivity of monel metal is practically the same as that of nickel, except in the short wave lengths where the reflective power is somewhat lower than that of pure nickel.

A new determination of the reflectivity of stellite gave values about 1 per cent. lower than previously observed in the visible spectrum, see B. S. Sci. Paper No. 342. The reflectivity of zinc is unique in having a deep minimum as 1μ followed by an unusually high value beyond 2μ.

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* Communicated by the Director.
[1] Technologic Paper No. 163.
[2] Scientific Paper No. 379.

OPERATION AND CARE OF VEHICLE TYPE BATTERIES.[3]
[ABSTRACT.]

THE preparation of this circular was begun by the Construction Division of the Army, using as a basis the results of tests made on tractor batteries at the Bureau of Standards. The circular contains a description of both the lead-acid and the nickel-iron types of batteries with the elementary theory of operation. Performance curves for both types are given showing the characteristics of constant current and constant potential charging, and for discharges at the normal 5-hour rate and at five times this rate. Later sections of the circular discuss the subjects of capacity, voltage, resistance, methods of testing, methods of charging, and directions for repairing lead-acid batteries. Appendices A and B contain War Department specifications for batteries of this type and for charging equipment. Appendix C gives record forms to be used in maintenance and Appendix D outlines the method of computing costs of operation. Appendix E is a glossary of terms used in connection with storage batteries.

THE SAYBOLT VISCOSITY OF BLENDS.[4]
By Winslow H. Herschel.
[ABSTRACT.]

IT has long been recognized that the viscosity of a mixture or blend of two oils is less than the arithmetical mean between the viscosities of the component oils. This is true whether viscosities are expressed in Saybolt seconds, poises or any other known unit of viscosity. For definite chemical compounds which are inert with respect to each other, a formula has been found which gives the viscosities of mixtures with great accuracy, but this formula can not be used with oils for which the molecular weights are not known.

For the purpose at hand the best available formula was found to be

$$\log \mu = v_1 \log \mu_1 + v_2 \log \mu_2 \tag{1}$$

where μ, μ_1 and μ_2 are the viscosities, in poises, of the blend and of the two component oils, and v_1 and v_2 are the percentage volume

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[3] Circular No. 92.
[4] Technologic Paper No. 164.

concentrations. Expressed in words, equation (1) shows that the viscosity of a blend is the weighted geometrical mean between the viscosities of the component oils, that is, the logarithms of the viscosities are additive.

If it is assumed that a Saybolt viscosimeter is used, the viscosity in poises may be obtained by the formula,

$$\mu = [.00220\, t - (1.80/t)\,]\, \gamma \tag{2}$$

where t is the time of flow, or Saybolt viscosity, in seconds, and γ is the density of the oil at the temperature of test, in grams per cubic centimetre.

It was found that the viscosities of blends as determined by test, agreed in some cases fairly closely with the viscosities estimated from equations (1) and (2), but the estimated value was always too low when there was a considerable difference between the viscosities of the component oils. For given component oils, the error increased as the amount of the lighter oil increased, reaching a maximum in a blend containing about 60 per cent. of the lighter oil. It was also found that the per cent. of error varied with the source of the crude oils, the maximum error being obtained if a heavy naphthene base oil was blended with a light paraffin base oil, and the minimum error being found with a blend of heavy paraffin and light naphthene oils.

In order to carry the difference in viscosity to an extreme, a heavy naphthene base oil was mixed with aviation gasoline, and the error in estimating the viscosity of the blend was found to be 221 per cent. But even in this case the viscosity determined by experiment was not as low as would have been estimated on the assumption that the reciprocal of viscosities was additive, a rule sometimes advocated as the true law of mixtures. Within the range of viscosities actually employed in blending operations, it was found that the maximum error in the viscosity calculated from the logarithmic rule would be 33 per cent. for naphthene base oils, or 25 per cent. for paraffin oils. A diagram was obtained for estimating the correction factor to be applied to viscosities of blends as calculated from the logarithmic rule. It is believed that with the help of this diagram the viscosity of a blend may be estimated with an error not greatly in excess of the error in determining the viscosity of the component oils.

Development of Ferro-vanadium Metallurgy.—B. D. SAKLAT-WALLA, general superintendent of the Vanadium Corporation of America, presented at the last (37th) general meeting of the American Electrochemical Society (April 8–10, 1920) a paper on this subject, which is interesting as showing how a metal which in earlier days had almost no applications is now of great importance in the industry. The chemical manuals of fifty years ago had little to say about vanadium compounds, except their possible use in making ink. Now vanadium steels are of extended use in several lines. Vanadium was, in common with several other elements, incorrectly classed as "rare." The real difficulty was the lack of any known deposit in large amount at one place. The metal is, indeed, one of the most widely distributed elements. It is diffused through all primitive granites and many sedimentary rocks and clays. Apart from the minerals in which it is the main constituent, it is found as an accessory in nearly three-score other minerals.

The discovery of a large deposit near Cerro de Pasco, in the Peruvian Andes in 1905, enabled the development of the vanadium alloys to be undertaken with greater success than previously. The chemistry of vanadium owes much to Berzelius, but the first suggestion of its application to metallurgy dates back to 1863, when Lewis Thompson suggested that it might affect iron in somewhat the same way that nickel does. The actual technical use, commercially, of vanadium steel began in 1896, when the Firminy Steel Works in France experimented with it in armor plates. Further researches continued; in 1904 Sankey and Smith published their investigations, and by a fortunate coincidence the Peruvian deposit was found shortly afterwards.

The author of the paper describes processes of manufacture of special steels and also the difficulties of obtaining the pure metal.

H. L.

The Largest Rolling Mill in the World. (*Electrician*, May 7, 1920.)—This distinction is claimed for the electrically driven, 20,500 h.p. installation recently put in service at Messrs. Dorman & Long's new Warrenby mills not far from Durham, England. It is a 42-inch plate mill, reversing type. Each roll is 3 ft. 6 ins. in diameter and 9 ft. 6 ins. long. Slabs weighing 10 tons with dimensions up to 7 ft. by 4 ft. 6 ins. by 1 ft. 6 ins. can be handled. Such slabs are rolled into plates three-eighths inch thick or over and attaining a width of 9 ft. and length of 100 ft. For two hours the output is 60 tons per hour; after this it is half as much for the remainder of the shift. The motor driving the rolls weighs 420 tons and the revolving parts 120 tons. In less than three seconds it can be reversed from 40 r.p.m. in one direction to the same speed in the opposite direction.

G. F. S.

NOTES FROM THE RESEARCH LABORATORY EASTMAN KODAK COMPANY.*

A STUDY OF THE SULPHUR DERIVATIVES OF BUTYL ALCOHOL.[1]

By H. LeB. Gray and Gurney C. Gutekunst.

[ABSTRACT.]

BUTYL SULPHIDE is prepared from butyl alcohol by first preparing sodium butyl sulphate and then distilling the crude reaction mixture with sodium sulphide. Butyl mercaptan is formed in large quantities by this method. The formation of butyl mercaptan is eliminated by refluxing the mixture with a large excess of sodium hydroxide and then distilling: a 72 per cent. yield is obtained. Butyl sulphide is also prepared by refluxing a mixture of butyl mercaptan and sodium butyl sulphate with a large excess of sodium hydroxide.

Dibutyl ether is prepared from butyl alcohol by refluxing a mixture of the alcohol and concentrated sulphuric acid at boiling temperature for 15 hours. Good yields are obtained by this method.

Butyl sulphide was oxidized to butyl sulphone by two methods. Oxidation by means of fuming nitric acid requires a large excess of the acid and a very impure product is obtained. The method of purification is long and tedious, and the yields obtained are very unsatisfactory. Butyl sulphone may be obtained in very small yield by oxidation of butyl sulphide with nitrogen dioxide. Oxidation of the sulphide with sodium permanganate was very successful. In this method the permanganate was added in small portions to the butyl sulphide with mechanical stirring. Large quantities of manganese dioxide separate. A 25 per cent. solution of sulphuric acid is added from time to time. The oil separating at the end of the reaction is poured off and the residual manganese dioxide extracted with ether. The oil obtained solidifies on cooling and is broken up and centrifuged. Practically pure butyl sulphone is obtained. One crystalization for alcohol is sufficient for purification.

TESTS OF X-RAY INTENSIFYING SCREENS.[2]

[ABSTRACT.]

FROM a practical standpoint, the most important characteristics of an X-ray intensifying screen are speed (intensifying factor), definition and graininess. The most reliable determination of intensifying factor was found to be by making exposures of parts of the human body, under the ordinary conditions of radiography, the intensifying factor being the ratio of the exposure without screens to the exposure with screens to give the same average density of negative. The intensifying factor varies with both the intensity and quality of the incident X-radiation; and for this reason, exposures made in a sensitometer or by any similar method, do not usually give the same factor as is obtained in practice. Slightly higher intensifying factors are obtained for thinner parts of the body than for the thicker parts. Double screens give much more contrast than single screens. Single screens give but little more contrast than is obtained upon films alone. Whether or not a double combination is faster than the single screen depends upon the properties of the screens and upon the intensity and quality of the X-rays striking the screen. The graininess of a screen may be tested by a flash test, giving a halftone density on the film when given standard development. The definition of screens may be compared by making radiographs of a 200-mesh wire gauze. Some screens show the meshes quite well while with others the meshes can scarcely be distinguished. The meshes are shown most clearly by the use of X-ray film without screens. A screen used as a double screen gives poorer definition than when used as a single screen. All these tests were made with no scattering material between the X-ray tube and the film. The wire screen test applied to the entire area of screens in cassettes showed loss of definition at the corners and edges, due to lack of contact of the screens with the film. Cassettes should give uniform pressure over the whole area of the films and screens should be sufficiently flexible to be flat under the pressure in the cassette.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

THE FOOD OF THE SMALL SEA HERRING AND AMMONIA AND AMINES AS END PRODUCTS OF ITS DECOMPOSITION.[1]

By F. C. Weber and J. B. Wilson.

[ABSTRACT.]

THE copepods, chiefly *Calanus finmarchicus, Pseudocalanus elongatus,* and *Temora longicornis,* and schizopods (shrimp) constitute the chief forms of feed of the small sea herring of the Passamaquoddy Bay region.

Very appreciable quantities of ammonia and amines were found when these forms of fish food were allowed to decompose. These products of decomposition were formed also when the two bacteria, *Bacillus Walfischrauschbrand* and *Bacillus B.,* associated with the feed were grown in pure culture. Skatole and indole as well were present in the culture media on which these bacteria were grown. Moreover, the presence of ammonia and amines was detected in the contents of the digestive tracts of "belly-blown," feedy fish.

From these results it may be concluded that the formation of ammonia and amines in the decomposing food is due to the action of the two bacteria always associated with the copepods and schizopods, whether they are taken directly from the water or from the digestive tracts of the fish.

Decomposition of the feed, accompanied by the evolution of gas when *Bacillus B* is present, is responsible for the bursting of the bellies of " feedy " fish.

THE MICROSCOPICAL EXAMINATION OF FLOUR.[2]

By George L. Keenan and Mary L. Lyons.

[ABSTRACT.]

USING special microscopical technic devised for the enumeration of the offal material in flour of various commercial grades, it was found that little uniformity in the matter of grading fin-

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* Communicated by the Chief of the Bureau.
[1] Published in *J. Am. Chem. Soc.,* **42,** 1920, 841.
[2] *U. S. Dept. Agr. Bull.,* **839,** issued April 23, 1920.

ished flours prevails in the different mills, and that there is a wide range in the offal content among flours of apparently the same commercial grades produced in these mills. It would seem that all mills do not composite their finished flours in the same manner. The effect on the offal content of the addition of various mill stocks may be determined by a microscopical examination of the constituent streams entering into the composition of a flour.

THE DIGESTIBILITY OF CHICKEN SKIN.[3]

By Edward F. Kohman and H. A. Shonle.

[ABSTRACT.]

Two metabolism experiments were conducted to determine the digestibility of chicken skin. Part of the fat was removed by extracting the skin with water, so that the skin, which was prepared for the experiment by being rolled into balls and fried, had a fat content of 26.3 per cent. and a nitrogen content of 3.03 per cent. This chicken skin was substituted for eggs, meat and milk in the ordinary diet of two subjects. The results showed that there was as good utilization of the nitrogen when from 65.1 to 67.5 per cent. of the nitrogen of the diet was supplied by chicken skin as when the same percentage of nitrogen was supplied by meat, eggs and milk.

PICKLE INVESTIGATIONS DURING 1919.[4]

By Edwin LeFevre.

[ABSTRACT.]

THE following results were obtained during the pickle investigations conducted by the Bureau during 1919:

1. Acid production is decidedly increased by the addition of 1 per cent. of corn sugar or molasses to the brine, corn sugar giving the best results. In the many cases where the sugar content of cucumbers is too low, the addition of sugar to the brine effects a stronger fermentation and better acid production.

2. Cucumbers fermented in a brine to which calcium carbonate and calcium sulphate, in amounts not exceeding those

[3] Published in *J. Biol. Chem.*, **41**, 1920, 469–472.
[4] Published in the *Canner*, **50**, 1920, pt. ii, 230–232.

found in many natural hard waters, have been added do not cure as well and the acidity is lower than when brines which do not contain these salts are used.

3. A very active fermentation and the highest degree of acidity noted in the experiments were obtained when lactic-acid-forming bacteria were added to the culture. It should be possible to secure practically the same results by adding to the tank a few gallons of brine from a freshly fermented barrel of pickles.

4. The addition of 1 per cent. of an edible form of lactic acid prevents a normal fermentation, but does not retard the curing of pickles.

5. Cucumbers of various sizes lose weight rapidly when submerged in a 10 per cent. (40°) brine, and, after remaining at the minimum for about three days, finally regain their original weight. From 40 to 60 days are necessary for this recovery in weight, corresponding very closely to the time required for a complete curing of pickles.

6. A brine of 10 per cent. salt concentration is the proper strength for starting a fermentation.

7. The length of time intervening between the gathering and brining of cucumbers has an important bearing on the formation of hollow pickles.

8. Cucumbers have a somewhat higher sugar content than has been previously indicated, the average sugar content for six varieties being found to be 2.18 per cent.

SAUERKRAUT PRODUCTION CONTROLLED BY HEAT.[5]

By Edwin LeFevre.

[ABSTRACT.]

As a result of investigations which showed that the organisms instrumental in fermenting sauerkraut require an optimum temperature of 86° F. and that these organisms fail in biochemical activity in the same ratio as the temperature falls below this temperature, experiments were conducted to determine whether it was possible under factory conditions to secure the proper degree of heat with cabbage, and, if so, how.

The suggestion that a favorable temperature might be secured by storing the cabbage in bins was disproved by a series of tests

which showed that only that portion of the cabbage which was well covered for a period of about four days was heated to any degree, by which time degenerative changes had set in. Moreover, it was found to be a physical impossibility to secure an even and satisfactory degree of heat by heating the outside of the tank containing the cabbage.

The experiments showed, however, that the heating of cabbage, with a view to promoting fermentation, may be effectively accomplished by the direct application of jets of steam to the shredded product; also that the use of an added culture of lactic bacteria aids in the fermenting process, although not to such an extent as to be considered of great practical importance.

Absorption of Arsenous Oxide by Metastannic Acid.—T. R. Briggs and W. J. Bartlett (paper presented at 37th meeting, April 8–10, of the Amer. Electrochemical Soc.) have found as follows:

At ordinary temperatures metastannic acid adsorbs arsenous oxide from watery solution, the action decreasing as the temperature rises. There is no trustworthy evidence that definite arsenites are formed, and probably Reichard's basic arsenite is merely an adsorption complex. Sulphuric acid and copper sulphate do not wholly prevent the action at ordinary temperatures, but interfere somewhat.

The old Gruessner and Badt method of removing arsenic from spent electrolytes seems to be an adsorption process. The presence of other substances more readily adsorbed may account for the unreliability of the method. The physical condition of the metastannic acid will have also a great influence on the result. Adsorbed arsenous oxide has a decided peptonizing action on the acid.

H. L.

Carnotite as a Source of Uranium.—In a discussion on a paper presented by Mr. Gin at the 37th meeting of the Amer. Electrochemical Soc. (April 8–10) it is stated that pitchblende is no longer the most abundant source of uranium, the carnotite deposits of Colorado and Utah having yielded far greater supplies in the last few years. Of course, another change has taken place in regard to the status of uranium minerals. Years ago the uranium content was the important feature, but now radium is the element sought. This fact has modified the metallurgy of uranium, since any process for extracting this metal which does not involve the obtaining of the maximum of radium from the ore must be abandoned. Uranium is now a by-product and somewhat of a drug in the market.

H. L.

NOTES FROM THE U. S. BUREAU OF MINES.*

LIQUID OXYGEN EXPLOSIVES.
By George S. Rice.

The scarcity of glycerine and ammonia during the war so affected the production and cost of dynamite and black blasting powder that the Bureau of Mines initiated experiments in the manufacture and methods of use of liquid-oxygen explosive, at its explosives' testing station at Pittsburgh, in March, 1917. After the armistice, while in Europe as member of the Commission for studying methods for rehabilitation of French and Belgian mines and works, I observed the progress made abroad with liquid-oxygen explosive. Germany was found to have used it extensively in non-gaseous coal mines, in quarries, tunnels, and for destroying French steel plants. The allied countries, being still able to import Chilean nitrates, had not used the explosive.

The Bureau of Mines obtained promising results in the preliminary experiments, and is continuing this work in the hope of making the use of liquid-oxygen explosive practical and economical in mines and quarries. As eminent physicists are promising improvements in liquifying apparatus that can be used for production of cheap oxygen, the explosive may become so cheap as to displace other explosives where conditions permit its use. Details on the use of liquid-oxygen explosive by Germany during the war, and the experimental work of the bureau are given in Technical Paper 243.

PERFORATED CASING AND SCREEN PIPE IN OIL WELLS.
By E. W. Wagy.

The ideal condition for maximum production from an oil well is an open, self-supporting hole toward which the oil moves from all directions without any barrier to its passage. When the walls of the hole are not self-supporting, but tend to run or cave, perforated casing, known as the " oil-string," must be used. In

* Communicated by the Director.

some instances the casing must be perforated after it has been inserted into the well. This calls for great care, in order to secure the maximum possible freedom of flow. Sometimes the casing has been so badly damaged by faulty perforating work that it has been necessary to redrill the well, at great expense, in other cases casing that was supposed to have been perforated has been found to be merely dented. A really satisfactory job requires the use of proper tools and considerable skill; details as to these tools and their use are given in Technical Paper 247 of the Bureau of Mines. Shop-perforated pipe is better wherever conditions permit its use. When the flow brings in much sand it is better to use screen pipe, which, though more expensive, is able to keep out the sand by means of its fine perforations. The size of the screen depends on the conditions to be met, as an economic balance must be struck between the amount of sand that may be handled and the resistance to free flow. A number of commercial types of screens are described in the paper mentioned above, and the effect of underground waters on these screens is discussed. When mud-laden fluid has been used in drilling, it is necessary to wash the mud out of the well before finally setting the casing. The details of procedure in carrying out this operation are given in the publication mentioned.

EVAPORATION OF CRUDE PETROLEUM.

By J. H. Wiggins.

THE evaporation of the volatile portions of crude petroleum causes the most serious loss to which it is subjected after it issues from the ground. The portion which thus escapes is not only the gasoline, but is the lighter, more valuable fraction of the gasoline, which is three times as valuable as an equal volume of the crude. An investigation made in the Mid-Continent field indicates that the yearly loss from this source amounts to 3 per cent. of the total amount of gasoline produced in the United States with an estimated value of over $25,000,000. Two-thirds to four-fifths of this loss can be prevented by protecting oil from free contact with air. The procedure to be followed and equipment needed to prevent exposure of the crude to the air varies according to the conditions existing at an individual well, and each operator of a lease or pipe line needs to study his individual problem.

MINOR NOTES.

Single Shot Blasting Unit.—An approval has been issued covering the first single-shot blasting unit to be approved under Schedule 12. The unit employs the Edison mine lamp battery, with special top and receptacle plug. The top and plug are arranged to prevent premature or accidental shots. The unit is approved for shot-firing only, and not for combination use.

Recovery of Gasoline from Still Vapors.—The Bartlesville station has completed an experimental refining plant and is studying methods of recovering gasoline from the still vapors.

Gas Masks.—The gas mask laboratory of the Pittsburgh station has begun experiments to develop a universal gas mask canister with all dry absorbents, sodium hydroxide to be used for the alkali. A tentative design for the canister has been completed. It will contain the following all-dry absorbents: (1) Charcoal, 700 c.c.; (2) cotton filter; (3) caustic pumice, 300 c.c.; (4) cotton filter; (5) hopcalite, 250 c.c.; (6) cooler; (7) silica gel. From preliminary tests of these substances, life against various gases is expected as follows: 3 per cent. CO, 60 minutes; 2 per cent. ammonia, $27\frac{1}{2}$ minutes; 1 per cent. gasoline or other organic vapors, $17\frac{1}{2}$ minutes; $\frac{1}{2}$ per cent. chlorine, 35 minutes; $\frac{1}{2}$ per cent. hydrogen cyanide, 194 minutes; $\frac{1}{2}$ per cent. SO_2, 51 minutes; $\frac{1}{2}$ per cent. phosgene, 42 minutes. Smoke, good protection.

Non-corrosive Priming Compositions.—Preliminary tests on non-corrosive priming compositions made at the Pittsburgh Station are now completed. It is expected to continue these tests in coöperation with some explosives manufacturing company. The best results were obtained with a mixture of fulminate, lead picrate, barium nitrate, and antimony sulphide. Three mixtures were prepared and tested, the one containing sufficient nitrate to oxidize all the carbon to carbon dioxide fired 80 rounds without missing. Mixtures with insufficient nitrate gave about 50 per cent. misfires. TNT and lead azide were found to be too insensitive to replace the fulminate.

Revival of the natural indigo industry in Bengal is described by HENRY E. ARMSTRONG (*Chemical Trade Journal and Chemical Engineer,* 1920, lxvi, 496). The eastern market will absorb the entire Indian output for years to come. The planters are devoting 2 per cent. of the sum realized on sales to research and propaganda. The decline in fertility of the indigo estates is being overcome by use of phosphate fertilizers. Extraction of the plants in cement vats may decrease the yield, for the Portland cement may give up lime to the steeping water and render it alkaline, while the microörganisms concerned in the liberation of the dyestuff from the plant are highly sensitive to alkali. The natural paste is far superior to the synthetic indigotin as a dye; with unspun wool, 6.5 parts of natural paste are equal to 8 parts of synthetic indigotin in dyeing heavy shades. Tests of a strictly scientific character made with piece goods on a practical scale show the natural product to be from 5 to 20, on the average 12.5, per cent. superior to the synthetic article. This superiority is ascribed to the presence in the natural product of other active constituents in addition to the blue indigotin which is the sole constituent of the synthetic product.

J. S. H.

Heavy Oil as Fuel for Locomotives. (*Le Génie Civile,* April 3, 1920.)—Before the war there was little interest in France in this use of oil except for the navy, but the destruction of the French coal mines by the Huns and their subsequent failure to deliver to France the promised quantities of coal have turned the attention of French engineers to the employment of oil-burning engines. The P. L. M. railway system took up the matter last October. The preliminary experiments gave favorable results, especially as regards the saving of time in getting up steam. In addition, this type of fuel showed itself well adapted for use on locomotives where there was an engineer alone without a fireman. Plans are now being carried out for the fitting of 225 locomotives with appliances for the burning of oil. This will be done both for shifting engines and for those used on long hauls.

G. F. S.

Fumigation with Formaldehyde.—D. W. HORN. (*Proc. Delaware County Institute of Science,* 1920) decides, after an elaborate investigation into the methods and efficiency of common forms of formaldehyde disinfection, that the bleach-chlorine method is the most generally applicable and is satisfactory. In carrying it out, the bleaching powder is simply placed in a bucket and the formaldehyde solution poured on it. For each 1000 cubic feet of space to be disinfected, 620 grams (one and one-third pounds) of bleaching powder and 800 c.c. (1.7 pints) of formalin should be used.

H. L.

THE FRANKLIN INSTITUTE.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, June 2, 1920.)

HALL OF THE INSTITUTE,

PHILADELPHIA, June 2, 1920.

MR. CHARLES PENROSE *in the Chair.*

The following report was presented for final action:
> No. 2748: Bullard Mult-Au-Matic. Howard N. Potts Medal awarded to Edward Payson Bullard, Jr., of Bridgeport, Conn.

The following reports were presented for first reading:
> No. 2739: Vacuum Cleaner.
> No. 2759: Screw Thread Comparator. Mr. R. W. Porter, a representative of the Jones & Lamson Company, was present and gave a demonstration of the Screw Thread Comparator.

R. B. OWENS,

Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, June 9, 1920.)

RESIDENT.

MR. CYRUS H. K. CURTIS, Publisher, *Public Ledger,* Philadelphia, Pennsylvania.

MR. HOWARD W. ELKINTON, Assistant Manager, Foreign Department, Philadelphia Quartz Company, 121 South 3rd Street, Philadelphia, Pennsylvania.

MR. CLARENCE P. FOWLER, Consulting Engineer, P. O. Box 27, Narberth, Pennsylvania.

MR. JOHN H. HIGGINS, Engineer of Tests, Camden Forge Company, Camden, New Jersey.

MR. JOSHUA R. H. POTTS, Lawyer, 929 Chestnut Street, Philadelphia, Pennsylvania.

CHANGES OF ADDRESS.

MR. E. S. BALCH, 1634 Spruce Street, Philadelphia, Pennsylvania.

CAPTAIN HENRY M. ELLIOTT, 352 State Street, Albany, New York.

MR. W. H. FINLEY, 412 North Washington Street, Wheaton, Illinois.

MR. W. M. GRAHAM, 113 North 19th Street, Philadelphia, Pennsylvania.

MR. W. C. A. HENRY, Room 1106, Syndicate Trust Building, St. Louis, Missouri.

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cent pieces bear date 1856, though they are now rather of numismatic than monetary interest.

The close analogies of nickel and cobalt extend through a long line of compounds, and as in the case of some of the other well-marked groups of elements, even the differences, by their peculiar contrasts are, in a sort of way, affiliations. Thus, nickel salts are usually green and cobalt salts red when hydrated, and, respectively, yellow and blue when anhydrous, and both these contrasting colors are complementary pairs. A striking exception in the properties of the two elements is found in the potassium nitrite double salts, potassium cobalt nitrite being so slightly soluble in water as to be available as means of determining potassium, while the corresponding nickel salt is quite soluble.

The mechanical execution of the book is excellent; clear type, good paper and correct printing. A large amount of information is given in the form of tables, which greatly increases the value of a work of this type. In the tabular statement of the composition of pure nickel and copper-nickel coins on page 100, the value of the United States coins is given as "5 paras and 5 centesimos," statements that seem to be typographical errors; if not, they are rather peculiar descriptions of our well-known " nickel."

HENRY LEFFMANN.

TREATISE ON GENERAL AND INDUSTRIAL INORGANIC CHEMISTRY. By Ettore Molinari. Second edition, translated from the 4th revised and amplified Italian edition, by Thomas H. Pope, B.Sc., F.I.C., A.C.G.I. XIX–858 pages, index, 328 illustrations and 2 phototype plates. Philadelphia, P. Blakiston's Son & Co. Price, $12 net.

The first edition of the English translation of this work found a ready sale, which is evidence of its merits, and an examination of the present issue shows that the high standard of the work is maintained. The translator seems to have done his work well, as the text does not show any Italian idioms.

Unlike most works on applied science, some space is devoted to a summary of the history of chemistry and over one hundred pages to explanations of the principles of science as now generally accepted, including a good deal on physical chemistry. So far as the history of the science is concerned, there is not much to commend. The subject is treated too briefly to permit of any satisfactory presentation of it. It is very unlikely that the chemists that use this book will care for the early stories, interesting as they may be to a few. The author goes even back of the Greek civilization, which is generally considered to mark the inception of modern science, and ascribes much higher value to Assyrian, Babylonian and Egyptian civilization than seems to be proved concerning them. He quotes without qualification a statement that oxygen and the composition of water were known many years before the work of Priestley and Lavoisier, but this statement rests upon a letter to *Chemical News* in 1887, in which a vague article is quoted from " old book on chemistry " (not

further identified), which book in turn quotes from the memoirs of the Academy of St. Petersburg. A claim as radical as this cannot be allowed to rest on such a questionable basis.

It is not, however, necessary to give more space to the discussion of minor questions, and the reviewer must turn to the body of the work; namely, the treatment of industrial processes; that is, the many procedures in industrial inorganic chemistry. Here there is great fulness of description, with abundant illustrations of the forms of apparatus. The classification is based mainly on the arrangement of the periodic system, now widely used, but some exceptions are made when special analogies seem to require them. For instance, the gases of zero valency are discussed in connection with nitrogen because they are regular ingredients of the atmosphere. A slight error is made in the note on the discovery of helium when it is stated that it was " discovered spectroscopically in the sun's chromosphere by N. Lockyer in 1867." It was really in 1868 that J. N. Lockyer observed a hitherto unrecognized and unassigned line in the spectrum of certain solar prominences. However, everyone seems to go astray on the history of helium. Doctor Molinari does not refer to the interesting recent application of helium as substitute for hydrogen in balloons and to the opportune discovery of it in considerable amount in the natural gas of some localities in the western part of the United States. But these facts have come too recently to general public knowledge to have been available when the pages were going through the press. It is now known, however, that at the time the armistice was signed, the United States had on the wharf at New Orleans, ready to ship to Europe, over seven hundred cylinders of compressed helium nearly pure for use in dirigibles. The present edition of Doctor Molinari's work will maintain the popularity that the first English edition secured and will be found of great use in the laboratory of both teaching and works chemists. The book is well printed on good paper and does credit to author, translator, printer and publisher.

HENRY LEFFMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS. Report No. 62. Effect of Altitude on Radiator Performance. Preprint from Fifth Annual Report. 13 pages, illustrations, quarto. Washington, Government Printing Office, 1920.

The paper discusses the effect on the performance of aircraft radiators of changes in atmospheric conditions at altitudes, and a method is developed for estimating the performance at altitudes from the performance at the ground and probable atmospheric conditions. Meteorological data are included from which atmospheric conditions at altitudes may be estimated, and the method is illustrated by application to two types of radiators. The degree to which a radiator should be shuttered at altitudes is considered briefly.

Report No. 64. Experimental Research on Air Propellers, III. Preprint from Fifth Annual Report. 35 pages, illustrations, plate, quarto. Washington, Government Printing Office, 1920.

This report presents the results of a series of tests in continuation of those previously reported in Nos. 14 and 30.

The tests covered in the present report include the following characteristics :

Four propellers of nominal pitch ratio 1.3, uniform pitch, straight face and with four combinations of form of blade and area.

Five propellers of nominal pitch ratios 0.5, 0.7, 0.9, 1.1, 1.3, all of uniform pitch, one area and blade form, and with the driving face made slightly convex by adding a crown of one-sixth the normal thickness of corresponding straight face sections.

Four propellers of nominal pitch ratio 0.7, uniform pitch, one blade form and area and four locations of the maximum thickness ordinate of blade section.

Three propellers of nominal pitch ratio 0.7, uniform pitch, one blade form and area and with three degrees of deformation of the leading edge through pushing forward by successive increments.

Through propellers distributed over the pitch ratios 0.5, 0.7, 0.9, 1.1, 1.3, all with one blade form and area, and with radially expanding pitch derived in each case on the assumption of a constant value of the angle of attack.

Several of the propellers of these series combine with those previously reported on to form more extended series with all characteristics constant except one, and that one varying by regular steps; others are intended to show, for a typical combination of other characteristics, the influence of some one feature; as, for example, the distortion of the leading edge, of the location of the maximum thickness ordinate of blade section.

The paper is accompanied by a brief description of a method of carrying on the tests, with a general discussion of the results with reference to the points most noticeably brought out by the various series formed, either by the models of the present report alone, or formed by them in conjunction with those covered by the earlier reports.

Report No. 70. Preliminary Report on Free Flight Tests. Preprint from Fifth Annual Report. 33 pages, illustrations, plates, quarto. Washington, Government Printing Office, 1920.

A report of the free flight tests conducted by the Committee to determine some of the characteristics of two full-sized JN4H airplanes. The maximum lift coefficient was found to be about 15 per cent. higher in free flight and came at about 4° larger angle of incidence than on the model, and it was possible by using full power to just reach the burble point in level flight. The machines in landing did not exceed an angle of about 12°, so that the landing speed deduced from the maximum lift coefficient of the model will in this case give the landing speed very closely. The maximum L/D of the machines was between 7 and 8, which is very near to that of the model. The velocity of the slip stream was determined for several motor speeds, and the results agreed well with theoretical values. The longitudinal stability, with locked and free controls, was investigated for a JN4H and also a DH4. While the former machine was found to be quite unstable, the DH4 was stable.

Report No. 72. Wind Tunnel Balances. Preprint from Fifth Annual Report. 40 pages, illustrations, plates, quarto. Washington, Government Printing Office, 1920.

This report is devoted to a detailed description, with numerous illustrations, of the balance designed for the wind tunnel at Langley Field. It treats of the sensitivity of the N.P.L. type of balance, the means provided for adjusting sensitivity and the effect on sensitivity of the rolling and yawing moments and cross-wind force which appear when the oscillations of the balance throw the plane of symmetry of the model out of line with the relative wind.

A discussion of the possible errors of the N.P.L. balance follows. Seventeen factors are listed, and the importance and the means of combatting each is discussed. Finally there are brief descriptions of four other types of balance (Eiffel, St. Cyr, Curtiss 2-axis, and Wright). The precision of each of these types and their most striking advantages and drawbacks are briefly discussed.

Report No. 74. Construction of Models for Tests in Wind Tunnels. Preprint from Fifth Annual Report. 18 pages, illustrations, plates, quarto. Washington, Government Printing Office, 1920.

This report contains a full description and discussion of the best methods to be employed in constructing models of aircraft and parts thereof for testing in wind tunnels. It includes material on the construction of model aerofoils, of fuselages, and of tail surfaces, and also on the types of models to be used for such special tests as those on pressure distribution. The amount of detail which it is desirable to include on a wind tunnel model is discussed, and the means of approximating the resistance of radiators and other appendages without constructing geometrically similar models are treated. In short, the report is a general handbook on the subject, and is designed to eliminate the difficulties which airplane designers often experience in obtaining models suitable for wind tunnel use.

Report No. 83. Wind Tunnel Studies in Aerodynamic Phenomena at High Speed. Preprint from Fifth Annual Report. 52 pages, illustrations, plates, quarto. Washington, Government Printing Office, 1920.

Experimental investigation of flow phenomena has heretofore been rather unsuccessful because of lack of adequate methods. The writers designed the McCook Field wind tunnel to investigate the scaling effect due to high velocities of propeller aerofoils. During the course of the experiments, however, it was found possible to visualize the air flow by the following method: The velocities of the air flow discovered by the writers offers a solution to one of the fundamental problems of aerodynamics. This problem is the quantitative empirical measurement of the phenomena of fluid dynamics pertaining to flight and air flow. The method described in the report for visualizing air flow depends upon the fact that the moisture in the air condenses as a fog when the temperature is reduced to the dew point, provided that there is a solid or liquid nucleus to start the condensation. In the McCook Field wind tunnel the temperature drop is brought about through expansion of the air during accelera-

tion, due to a drop of pressure of 100 inches of water. The relative humidity of the atmosphere can be artificially raised if too low, and the necessary nucleus for condensation is provided by the model tested. Flow vortices become readily visible, and the report contains many photographs showing the air flow past an aerofoil under different conditions.

Copies of the above reports may be obtained upon request from the Committee.

R.

PUBLICATIONS RECEIVED.

National Advisory Committee on Aeronautics: Technical Notes. No. 1. Notes on Longitudinal Stability and Balance, by E. P. Warner. 13 pages, diagrams. No. 2. Airplane Performance as Influenced by the Use of a Supercharged Engine, by George de Bothezat. 7 pages, diagram. No. 3. Notes on the Theory of the Accelerometer, by E. P. Warner. 13 pages. No. 4. The Problem of the Helicopter, by E. P. Warner. 18 pages, diagrams. 4 pamphlets, quarto. Washington, 1920.

U. S. Bureau of Mines: Bulletin 196, Coal-mine Fatalities in the United States, 1919, by Albert H. Fay. 86 pages. Monthly Statement of Coal-mine Fatalities in the United States, March, 1920, by W. W. Adams. 8 pages. Technical paper 227, The Determination of Mercury, by C. M. Bouton and L. H. Duschak. 44 pages, illustrations, plate. Technical paper 243, Development of Liquid Oxygen Explosives During the War, by George S. Rice. 46 pages, illustrations, plate. Technical paper 245, Quarry Accidents in the United States During the Calendar Year 1918, by Albert H. Fay. 51 pages. Technical paper 247, Perforated Casing and Screen Pipe in Oil Wells, by E. W. Wagy. 48 pages, illustrations, plates. 6 pamphlets, 8vo. Washington, Government Printing Office, 1920.

Appreciation of Industrial Scientific Research. (*Electrician,* May 7, 1920.)—In commenting upon Gherardi and Jewett's paper on Telephone Repeaters, recently read before the American Institute of Electrical Engineers, the following comment is made: " American enterprise has, ever since the inception of commercial telephony, been largely responsible for the commercial development of the many features contributing to the modern telephone art as practised throughout the world; and the development and application of the thermionic telephone repeater to commercial service is no exception to this rule. The early years of the war period have hindred development in this country to an extent which is hardly realized in America, but in spite of this it is hardly possible to doubt that American appreciation of industrial scientific researches compared with the British attitude toward the same subject has been a very great factor in determining America's present leading position in telephony."

G. F. S.

CURRENT TOPICS.

Determination of Methyl Alcohol.—The detection and determination of methyl alcohol have become important problems in analysis of late years, owing to its use as an adulterant and substitute for ethyl alcohol and its poisonous qualities. S. B. Schryver and C. C. Wood (*Analyst,* 1920, vol. xlv, 164) describe a process depending on the oxidation of the alcohol to formaldehyde and the determination of this by a special colorimetric method. The general outline of the procedures are as follows:

For the determination of methyl alcohol in water alone samples of 5 c.c. each of the solution are placed in test-tubes about 15 cm. by 2 cm., and 5 c.c. of solution of ammonium persulphate solution of differing concentrations added successively. The persulphate solutions are made up in known concentration graduated by some simple ratio. The tubes are heated in boiling water for ten minutes, when 1 c.c. is withdrawn from each tube by a pipette, placed in a series of tubes, each of which contains 1 c.c. of 1 per cent. of phenylhydrazin hydrochloride, to which mixtures are then added 1 c.c. of a 2.5 per cent. solution of potassium ferricyanide and 3 c.c. of concentrated hydrochloric acid. It will be found usually that the concentration of the methyl alcohol will lie between two limits, namely, one in which the amount is such that the persulphate is sufficient to oxidize completely the formaldehyde first formed, and a limit in which some of the liquid still gives a reaction for formaldehyde after the heating. A second series of experiments can then be carried out in which the persulphate is used in strengths ranging between the limits ascertained. The mixtures can be adapted to the degree of accuracy desired. For each concentration of methyl alcohol there corresponds a definite concentration of persulphate just sufficient under the conditions of the experiment to oxidize all the formaldehyde formed in the reaction. A considerable number of test analyses are given.

An attempt to determine methyl alcohol in the presence of ethyl alcohol by the above method failed, and the following modification was made:

Ten c.c. of ethyl alcohol, containing methyl alcohol, are diluted with 50 c.c. of water, 5 c.c. of this mixed with 5 c.c. of a 1 per cent. solution of the persulphate, and heated for ten minutes in a test-tube provided with a short air condenser. One c.c. of this mixture is added to 1 c.c. of a 1 per cent. solution of phenylhydrazin hydrochloride and heated in boiling water for five minutes. When cold, 1 c.c. of a 2.5 per cent. solution of potassium ferricyanide and 3 c.c. of concentrated hydrochloric acid are added. A pink liquid is

produced if methyl alcohol was present, which can be compared with tints produced by the same process from samples containing known amounts of the two alcohols. A colorimeter will give better results. Test analyses show that the method is accurate to about 1 per cent. when the amount of methyl alcohol present ranges from 0.5 to 5.0 per cent. For more accurate results the pink solution may be diluted with 70 c.c. of water and compared with standards of known composition. The commercial sample of ethyl alcohol used in the experiment, gave a slight formaldehyde reaction when treated in the manner described, but it is impossible to say whether this is due to the presence of impurities or to the slight production of formaldehyde from the ethyl alcohol itself.

A slight modification of the method has been found satisfactory in the determination of methyl alcohol in acetone.

H. L.

The Crystallography of Snow. E. T. WHERRY. (*Monthly Weath. Rev.*, 1920, vol. xlviii, 29.)—The beauty and almost endless variety of forms of snow crystals have been matters of interest for many years, but only very few studies have been made from the purely scientific point of view. Doctor Wherry's paper presents a consideration of the forms from the point of view of the crystallographer. Previous investigators have shown that snow and ice crystals are assignable to the trigonal system (sometimes termed the trigonal subsystem of the hexagonal system), and these forms have been found to be different at opposite ends, frequently enough to place them in the hemimorphic class of the system. Ice does not rotate the plane of polarized light, which shows that it belongs to the particular class known as trigonal-pyramidal, of which tourmalin is the best-known example.

The trigonal system is characterized by the presence of two kinds of axes, three of one and one of the other. The three similar axes lie in the same plane crossing each other at angles of 60°; the other, called for convenience, the unique axis, is perpendicular to this plane. In this class the opposite ends of the unique axis are crystallographically unlike, but snow crystals are usually so developed that this feature is obscured, though occasionally it is developed in striking manner. The nucleus from which a snow crystal starts, probably consists of a single molecule of ice, which contains three molecules of H_2O. As new material attaches to this the results will differ according to the rate of accretion. If the growth is very slow, the crystal may retain the form throughout, but with rapid growth the crystals become elongated and needle-like, and when the growth occurs in several directions around an axis of symmetry, a skeleton of a possible solid form will be produced.

The paper is illustrated with numerous figures mainly from a paper by Shedd (*Monthly Weath. Rev.*, 1919, vol. xlvii, 691) and taken by W. A. Bentley.   H. L.

Production of Synthetic Camphor in the United States. (*A. C. S. News Service.*)—The great demand for camphor in the manufacture of celluloid and also for medicinal use, coupled with the present restrictions by the Japanese government on the exportation of the natural product has stimulated the manufacture of the substance from spirits of turpentine.

Although in popular usage the term " camphor " is applied to a substance which is derived from an aromatic tree grown largely in Japan, Formosa and China, there are several other kinds. Camphors are mostly crystalline solids obtained from plants. Technically, they are volatile, oxygenated hydrocarbons, possessing a peculiar odor, and can be prepared artificially by chemical processes.

It has been known for years that a grade of camphor closely resembling the Japanese variety could be made from spirits of turpentine. It has only been recently, however, owing to commercial conditions, that the manufacture of synthetic camphor was instituted on a large scale. As approximately nine-tenths of all the turpentine produced in the world is distilled in the United States, chemists believe that the manufacture of American camphor will develop into a large industry. As a result of the World War and of the high cost of labor, spirits of turpentine is quoted at $2 a gallon, or about four times its price in *ante bellum* days. Although it is improbable that turpentine can ever be made profitably at the old figure, it may decrease in price sufficiently to give the American camphor factories a good safe margin on which to fight the Japanese trade. Even if the manufacturing chemists of the United States are unable to much undersell the Japanese product now, they should be in a position to counteract the monopoly of Nippon and improve the market. Those desirous of fostering the chemical independence of the United States declare that the founding of an American camphor industry is in line with the effort to make this country independent of the German cartels, which for years dominated the dye trade of the world.

Jelly.—According to C. H. CAMPBELL (*Journal of Industrial and Engineering Chemistry*, 1920, xii, 558–559), acid, pectin, and sugar must be present in the proper proportions in order to obtain a good jelly. A delicate quality, resembling that of home-made jelly, is imparted by a pectin content of 0.75 to 1.0 per cent., while 1.25 per cent. pectin produces a fine commercial jelly. The acidity, calculated as sulphuric acid, must lie between 0.27 and 0.50 per cent.; an acidity of 0.3 per cent. is necessary to produce a jelly of good quality. An excess of sugar produces a soft jelly, an insufficient amount of sugar a tough product. The yield of jelly becomes greater as the amount of sugar used increases. The actual yield (volume) of jelly does not depend on the pectin content.   J. S. H.

Zinc and Copper, Regular Constituents of the Human Body.—

According to E. ROST (*Die Umschau,* 1920, xxiv, 201–202), zinc and copper occur in the human body; the amount of zinc, calculated as millegrams of metal per kilogram of organ, was: Liver, 52 to 146; muscle, 47 to 52; brain, 11; copper was also present, but in lesser amount. Zinc enters the body with the food, and is derived directly or indirectly from the soil, or from water which has flowed through galvanized iron pipes. The zinc content of various foodstuffs (milligrams of zinc per kilogram of food) was: Beef, veal, pork, mutton, and horse meat, 26 to 50; beef liver as high as 83; horse liver as high as 339; sea fish, 4; hens' eggs, 9.8 (equal to 0.5 milligram zinc per egg); bread, 5 to 8; potatoes, 2.3; dried vegetables, 6.13. The amount of zinc present in each litre of milk was: Cows' milk, 3.9; goats' milk, 2.3; human milk, 1.3. Swiss cheese, beet sugar, and beer did not contain zinc. Copper was present in smaller amounts in the meat and the liver, though one beef liver contained 119 milligrams of copper per kilogram of organ. Both zinc and copper are regular though accidental constituents of the organism—human, animal, and plant—under present conditions. The quantity of these elements normally present in the food is unavoidable, and does not injure either the digestive organs or any other part of the body. However, if vessels either made of, or coated with, zinc be used for cooking or storage of foods which are acid or may become acid, then the food may contain zinc salts to such an extent that injurious effects may be produced on the system.

J. S. H.

Dehydration is discussed in a paper by SAMUEL C. PRESCOTT on "Dried Vegetables for Army Use" in the *American Journal of Physiology,* 1919, xlix, 573–577. In the process of dehydration, water is rapidly removed from vegetables, fruits, and other foods through evaporation by air currents or vacuum combined with moderate heat. The cellular structure should be unchanged. When cooked, dehydrated foods return approximately to the bulk and character before drying, and have the color, flavor, and texture of cooked fresh material. By dehydration a food may be reduced as much as 90 per cent. in weight and as much as 50 per cent. in bulk; the product is more easily transported and keeps well for a long period of time. During the war approximately 40,000 tons of dehydrated vegetables were shipped overseas to the United States forces. Experiments on guinea-pigs have shown that a ration composed entirely of dried vegetables of non-acid character contains little, if any, of the antiscorbutic substances, while a ration composed of dry fruits of an acid character, such as tomatoes, oranges, and lemons, does not produce scurvy even on long-continued feeding.

J. S. H.

The Otophone: an Instrument for Reading by Ear. E. E. FOURNIER D'ALBE. (*Nature*, May 6, 1920.)—By a series of lenses the image of a straight incandescent lamp filament is thrown on a sheet of paper. Between the filament and the lenses is interposed a disk whose radius is parallel to the filament. The disk is pierced with five concentric sets of square holes, the innermost 24 in number and the outermost 42. The disk transforms the line image of the filament into a series of points. The disk revolves thirty times per second. Thus there are from 1260 to 720 interruptions of the light per second. Let a selenium cell be placed near the flickering row of dots. From each of these light is diffusely reflected to the selenium, whose electrical resistance is thereby changed. If the selenium is joined in series with an electric cell and a high resistance telephone receiver, a note will be emitted by this which is compounded of the tone caused by the five intermittently illuminated spots of light. Take the spot nearest the centre of the disk. Seven hundred and twenty times per second the light is cut off from it and the same number of times the resistance of the selenium varies and just as often the current strength varies and the diaphragm of the receiver will move with each change of current. Hitherto it has been assumed that all the spots of light fall on white paper. Let one, however, fall on a part of the paper covered with black ink. From this no light will be diffusely reflected to the selenium and the compound note from the receiver will lack the tone corresponding to the frequency of this spot.

In the use of this instrument by the blind the group of five spots of light is made to travel along a line of print. The note changes with the number of spots falling upon the print. Each letter has a complex of sound characteristic to itself. One blind girl reads habitually at the rate of 25 words per minute.

G. F. S.

Effect of Changes of Pressure on a Galvanic Cell. W. M. COLEMAN. (*Proc. Phys. Soc., London*, vol. xxxi, p. 57.)—An increase of pressure of 240 mm. of mercury caused the current coming from a cell to increase by 5 milliamperes, or about 12 per cent., while a decrease of the same extent was followed by a similar decrease of current. These changes were observed when the pressure varied rapidly. They rarely followed slow changes of pressure.

Again, a long cell two metres from end to end was examined first with one end down then with the other. When the cell was horizontal the current was 4 milliamperes; when the zinc end was down the current was six of the same units. Upon putting the copper end down the current grew less.

The author explains these effects by changes of polarization due to dislodgement of gas.

G. F. S.

Eka-cesium.—According to the periodic law, an element, as yet undiscovered, probably exists, and belongs beneath cesium in the group of the alkali metals or group I. This element is tentatively designated eka-cesium. L. M. DENNIS and R. W. G. WYCKOFF of Cornell University have made "A Search for an Alkali Element of Higher Atomic Weight Than Cesium " (*Journal of the American Chemical Society*, 1920, xlii, 985–990). The raw material was 3500 grams of the very rare mineral pollucite, which is a silicate of aluminum and cesium and contains over 30 per cent. of cesium oxide. The mineral was decomposed by prolonged boiling with concentrated hydrochloric acid, and a solution of the alkali metals present in it was thus obtained. The alkalies were then subjected to fractionation (1) by precipitation of the chlorides with hydrogen chloride, (2) by solution of the perchlorates, (3) by crystallization of the sulphates, (4) by solution of the alums. "In these several processes those fractions in which the higher analogue of cesium, eka-cesium, might be expected to be concentrated were examined by means of the arc spectra of the solid material in the red, the visible, and the ultra-violet portions of the spectrum. In no case were there indications of the existence of eka-cesium."

J. S. H.

Relative Nutritive Value of Meat and Milk. (*Jour. Ind. Eng. Chem.*)—The Committee on Food and Nutrition (National Research Council) states as the result of recent investigations, that about 18 per cent. of the energy of grain fed to cattle is recovered for human consumption in milk, but only about 3.5 per cent. in beef. Similarly, crops on a given area will yield four or five times as much protein and energy when fed to dairy cows as when used for beef production. In providing mineral substances and vitamines, the milk of the cow contrasts even more favorably with the beef animal. The vitamines and calcium salts contained in hay and grain are stored in the muscular tissue only to a slight extent, but are in relative abundance in milk.

H. L.

The value of the synthetic mannitol olive oil as a food has been studied by WILLIAM D. HALLIBURTON, JACK C. DRUMMOND, and ROBERT K. CANNAN of King's College and the Cancer Hospital, London (*Biochemical Journal*, 1919, xiii, 301–305). The experimental animals were rats. Under similar conditions the utilization of the mannitol olive oil and of olive oil by the animals was practically the same, being 95.8 per cent. for the former and 96.6 per cent. for the latter. No toxic action followed the prolonged administration of the mannitol olive oil to rats as part of their ration.

J. S. H.

Photographing a Mirage.—In the *Proc. Roy. Soc. of Edinburgh* (1918–1919, vol. xxxviii, 166), A. C. RAMAGE gives an account of a mirage frequently observed on a public road in Scotland. The first observation was made on a day of bright sunshine, the appearance being of pools of water reflecting the foliage very vividly, and further down the road images of other pools. The road was perfectly dry at the time. The air over the road was vibrating, and the line of telegraph wires with white, insulators seemed to be also vibrating. Walking towards the apparent pools they vanished, but on retracing steps again appeared. The paper describes in some detail the several appearances, which were noticed distinctly by other persons. The road at the point at which the phenomena occur is made up of bitumen and road-metal and is sheltered.

The most interesting fact about the observation is that the mirage has been photographed. A brief account of this result is given in a later issue of the proceedings (1919–1920, vol. xl, 33), in a communication by the General Secretary, who states that similar appearances have been reported from various sections of the country, and Mr. C. F. Quilter has obtained five excellent photographs, showing all the important features of the mirages. In one, taken in August, 1919, the shaded side of a telegraph pole with neighboring trees, and a white-walled house beyond were distinctly seen as if reflected from a pool in the middle of the road.

H. L.

Photo-synthesis.—BENJAMIN MOORE and T. ARTHUR WEBSTER (*Proceedings of the Royal Society of London,* 1920, xci, B, 201–215) have demonstrated that the unicellular fresh-water algæ can fix atmospheric nitrogen, grow, and synthesize protein in the absence of all other sources of nitrogen, provided an abundant supply of carbon dioxide be available. However, the oxides of nitrogen in the atmosphere are utilized more readily than the free element. These algæ are able to utilize formaldehyde and methyl alcohol as food and to produce marked growth when these compounds are the sole source of carbon; however, these compounds must be fed in sufficiently high dilution, otherwise they are poisonous to the living cell. This utilization of formaldehyde and methyl alcohol as food is of importance, for these compounds are the first products of photo-synthesis.

J. S. H.

THE DESIGN OF WAR VESSELS AS AFFECTED BY THE WORLD WAR.*

BY

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Member of the Institute.

THE Battle of Trafalgar was fought October 21, 1805, or
early in the nineteenth century. In the early part of the present
century the tactics employed in that battle were still being dis-
cussed, but although Nelson's Flagship, the *Victory*, is preserved
by England at Portsmouth, it is of no interest from a material
point of view to designers of war vessels of the present day.
Similarly, with the rapid engineering development of naval
material which has been going on for more than fifty years and
bids fair to continue, the material lessons from the World War
must be gathered within a comparatively short time. Even so, to
answer fully the question, " What has been the effect of the World
War on warship design? " is not as yet possible. For years it
will be necessary to collate and study an enormous mass of experi-
ence, some written, some oral, some originating from the respon-
sible controlling bodies of the great navies, and much from indi-
viduals, including not only those of great eminence, but many
whose names will never emerge from comparative obscurity,

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* Presented at the Stated Meeting of the Institute held Wednesday,
April 21, 1920.

[Note.—The Franklin Institute is not responsible for the statements and opinions advanced
by contributors to the JOURNAL.]

though their experience in the aggregate may in the long run exercise a dominating influence.

As a practical proposition the full effect of war experience will be demonstrated in concrete form only after service opinion has been crystallized and become definite in direction as a result of study and discussion by a large number of officers. Certainly that will be the case in the American Navy where the organization is such that service opinion necessarily controls policy in the development of naval types. The service is a customer of the naval designer, and although the latter may influence and at times interpret and lead service opinion, the customer will have what he demands. What I say to-day must therefore be taken more in the light of a discussion of this intensely interesting subject, than as a hard-and-fast laying down of principles or expressions of final opinion.

Let me call attention at once to the fact that, after all, there has been nothing startling or revolutionary brought about by the experience of fifty-one months of war. There has mainly resulted an intensive development of each of the accepted types which existed at the outbreak of the war and which were the results of many years of study, experiment, and practice in all of the great navies of the world. It is true that some new types have appeared, but with one exception, namely, aircraft carriers, they have been of minor importance when measured by the cost and time required for production.

When we consider types and not details, we must not look only to the few naval battles of the World War which can justly be classed as major actions for the influences affecting our naval construction of the future. It is necessary to consider the particular trend of naval events, the accumulated experience, and the principal phases of naval activity during the more than four years of hostilities.

The first of these must naturally be the causes which gave not only the initial but the continuing command of the sea to the Allies. We know that at the outbreak of the war all German mercantile vessels quickly disappeared from the high seas, being either held in their own ports or promptly interned in neutral ports. On the other hand, Allied commerce proceeded on its way. It was not the great British Battle Fleet which the German merchantmen feared, for they knew that this Fleet would be con-

centrated at one point within easy striking distance of the German coasts and therefore it could be easily avoided. What they feared were the Allied Cruisers, Auxiliaries, Destroyers and light vessels of every class. Just as the few German Cruisers which were at large were captured or sunk within a few months, so could this cloud of Allied light craft have been swept from the seas had the German heavy fighting forces been able to operate without first giving battle to the superior British Battle Fleet. They were unable to do this at any time during the war. As a result every military effort of the Central Powers afloat and ashore was made more difficult because of the slow but sure throttling of their economic and industrial life. Without the British Battle Fleet the blockade of Germany would have been ineffective. This factor had such a determining influence, both on the duration and final outcome of the war, that the types of vessel which make up the main fighting fleets are more firmly established than ever as the essential ones contributing to naval power. If these great battleships and battle cruisers disappear, either in the near or the distant future, it will be as a result of engineering progress and the invention and perfection of new weapons and not as a result of the World War.

Battleships and battle cruisers were in actual conflict with vessels of the same type and power on only two occasions: at the Dogger Bank on January 24, 1915, and at Jutland on May 31, 1916. These actions, however, do not by any means represent the sum total of their activity. When the location and activity of the German Cruiser Squadron in the Pacific was disclosed by the tragedy off Coronel, two battle cruisers at once sailed to search out and destroy this troublesome squadron. Perhaps they were lucky in coming into contact with the enemy immediately, but the celerity and success with which they accomplished their mission at the Falkland Islands gave a great impetus to the favor in which this type was held by naval men. The immediate effect of this sentiment was seen in the British battle cruisers *Repulse* and *Renown,* which represent the extreme of the type; that is, armor and gunpower were sacrificed to speed to an even greater extent than in the original battle cruiser. These were quickly followed by an even greater extreme, the *Courageous, Furious* and *Glorious,* which can be denominated either small light battle cruisers or enormously large light cruisers, as they

have the largest guns characteristic of the former and the total absence of armor protection characteristic of the latter, while possessing the high speed common to both. The battle off Dogger Bank served only to confirm the conclusions on which these two classes of ships had been laid down. In this engagement, the rival battle cruisers met for the first time, with the result that those on both sides demonstrated their ability to stand heavy punishment without succumbing to fatal damage. Even the older German cruiser *Blucher*, which was inferior in gunpower, protection and speed to all of the others, succumbed only after surviving for a considerable period of extremely heavy punishment. If there had been no further war experience with the battle cruiser type it is likely that the idea that protection is not im-
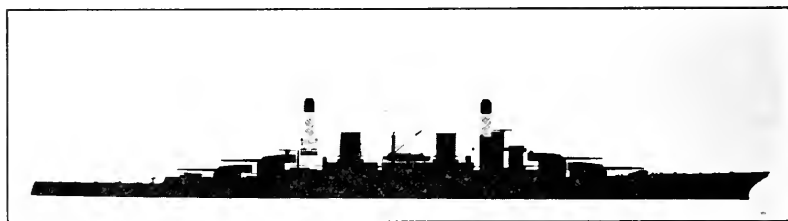
U. S. BATTLE CRUISERS NOS. 1-6.

Principal characteristics:

Displacement ... .43500 tons	Speed............................33.25 knots
Length......... ....850 feet	Battery...............8-16″ and 16-6″ guns
Horsepower...... 180000	Torpedo tubes 4-21″ submerged and 4-21″ above water

portant for them would have prevailed, and the combination of extreme speed, guns of the largest size, and the minimum of protection might have been in favor for some years. But the Battle of Jutland gave a rude shock to opinions based on earlier actions.

The Battle of Jutland is easily the foremost single event of modern naval history. The controversial phases of the tactics employed in this battle are only of interest to the naval designer in so far as the material in the two fleets influenced the judgment and decisions of the high command on each side, and to the extent that new instruments of naval warfare, not then available but developed since, would have exercised a determining influence in the tactics employed; in the latter class comes the use of aircraft, and I will have occasion later in this paper to refer to the

use and influence of aircraft in naval operations from the designer's point of view. By far the most important aspect of this engagement to the designer is the manner in which the various types of vessels engaged fulfilled the functions for which they were originally designed. In regard to type, the first outstanding
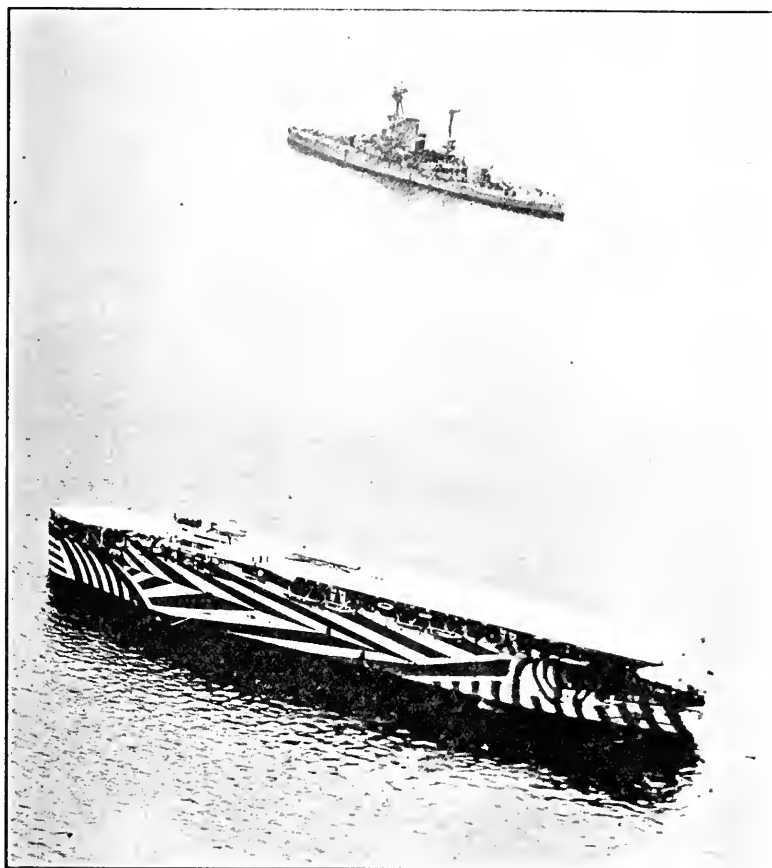
BRITISH AIRPLANE CARRIER *ARGUS.*

fact is that battle cruisers must inevitably play an important rôle in major fleet actions. Each side in turn, first the Germans and then the British, used their battle cruisers to lead the whole or a portion of the enemy's fleet to contact with the main body of their own fleet. In fact, with the single exception of the *Warspite,*

it was the battle cruisers on both sides that stood the brunt of
the action and received the lion's share of punishment from the
enemy. If the battle had been fought to a finish between the
battleships, there might have been a different story to tell. The
losses and heavy damages sustained by the vessels of battle
cruiser type bear out to some extent the pre-war contentions of
those who maintained that it was not fit to take its place in the
line of battle. On the other hand, excepting their greater vul-
nerability, it cannot be denied that they acquitted themselves with
credit even when pitted against the more heavily armed and

BRITISH AIRPLANE CARRIER *ARGUS*.

armored battleship. Furthermore, not only was the value of
their great speed demonstrated, but also the value of one side
holding the speed gauge over the other was shown, for, it was
due to the possession of higher speed by the British that the
German Fleet, at the end of the second phase of the battle, found
itself in a position which was so bad tactically that the German
Chief-of-Staff is quoted as saying that if any Admiral had
involved himself in such a position in peace time manœuvres he
would never again have obtained a command afloat. Another
result from this action of general influence on type is found in
connection with the use of older battleships, generally referred
to as of the " Pre-dreadnaught " era. The German Fleet included

one squadron of vessels of this type, and this squadron not only failed to be of any essential assistance to them but proved actually to be a handicap on their freedom of manœuvre. The force of this lesson was shown by the fact that subsequent to the battle most of the German battleships of this type were retired from active commission. The material weakness of this type of older ships, when opposed to the most modern weapons, was shown in the case of the *Pommern*, which blew up and sunk immediately as a result of a single torpedo. The ineffectiveness of these older ships, as shown by many incidents of war, will be referred to later.

The ability of the large, modern, heavily-armored ships not only to survive, but to continue in action after the most severe punishment, was perhaps best shown by the British battleship *Warspite*, which, due to an unfortunate accident to the steering gear, sheered out of the battle line and made two complete circles within short range of the German Fleet. This vessel was hit by major calibre shell between 20 and 25 times. The net result of this tremendous hammering was that one out of eight 15-inch guns was put out of action; there was no damage of any kind to her main machinery plant; the upper works and unprotected portions of the ship were riddled; communications were interrupted to a considerable extent; and some compartments at and below the waterline were flooded by water which came in from above, but none of the main compartments were affected to such an extent that the entering water could not be handled by the pumping arrangements provided. In short, although the ship had lost a certain amount of her margin of safety, due to decreased buoyancy and stability, and her speed had suffered on account of increased resistance due to her greater draft, she was entirely capable of resuming action after adjustments to her steering gear.

The *Marlborough* was another example of a battleship continuing in action after receiving what we were inclined formerly to consider would be a disabling attack. This vessel, although of the " Dreadnaught " era, has not what is now considered a highly efficient form of protection against torpedo attack, yet, after being struck by a torpedo, resulting in the flooding of a number of compartments, which produced a list of about 7 degrees, the vessel continued in action at a speed of 17 knots.

Similarly, the German battleship *Ostfriesland* (of the "Dread-

naught" era) was struck by a torpedo which produced some flood-
ing, but the vessel was otherwise unaffected and continued on with
the German Fleet.

No other British battleships received any considerable amount
of punishment, but three of the modern German ships of this class
received, respectively, 7, 7 and 13 hits from major calibre guns,
but none of them were disabled or even damaged to an extent
sufficient to prevent them continuing in action. The *Markgraf,*

EAGLE CLASS.

Principal characteristics:

Displacement	500 tons	Speed	18 knots
Length	200 feet	Battery	2-4″ guns
Horsepower	2500	Depth bomb projector	1 Y-type

which was struck 13 times, is a particularly illuminating example
of the amount of punishment which a modern heavily armored
ship can stand. The only damage affecting the efficiency of the
ship was the cutting of the communications from the masthead
fire control positions, and this only resulted in shifting the control
to the lower armored station provided for this purpose. The
casualties on this ship were likewise remarkably low, as there
were only 8 dead and 9 wounded, or only a little more than one
casualty for each major calibre hit.

One particular class of hit of special interest to American
designers is that in which turrets or their barbettes have been hit.
Taking the case of 4 British and 4 German vessels which suf-
fered heavy damage, it is found that out of a total of about 116
hits, 19, or 16.5 per cent., were on turrets or barbettes, of which
16 were struck. Of this number, 4 were completely put out of
action and one gun in each of four others was disabled, while
the remaining 8 escaped without serious damage. In other words,
out of 66 big guns carried by these ships, the emplacements of
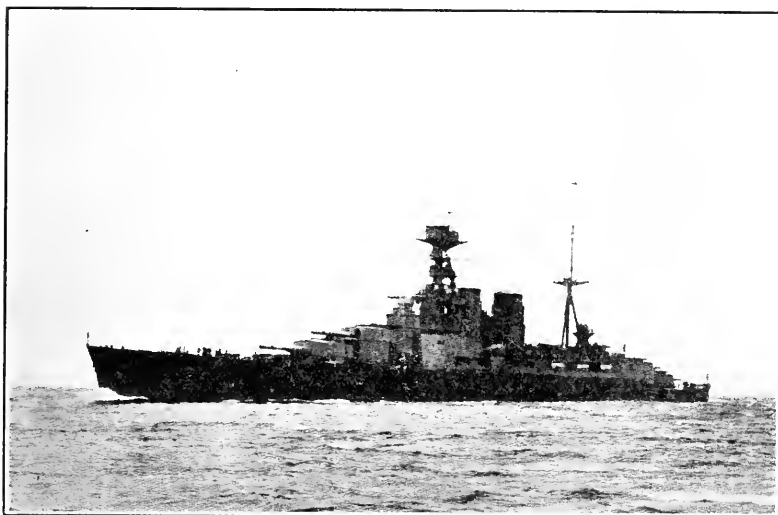
BRITISH BATTLE-CRUISER *HOOD.*

Displacement ....41500 tons	Speed............................ 31.25 knots
Length .... 860 feet	Battery ....8-15″ guns
Horsepower 144000	

32 were struck, but only 12 were sufficiently damaged to prevent
their further use. This comparatively low proportion of casualty
in the major offensive armament, together with the demonstration
of the ability of the mechanism of a turret to continue to function
even after the turret has had a direct hit, appears to dispose of
the argument of "too many eggs in one basket" so frequently
advanced against the American three-gun turret.

Turning to the damage sustained by the battle cruisers, one's
attention is naturally taken first by the tragic loss of the three
great British vessels of this type. Although in one case the

Germans claimed a torpedo hit on one of them, it is generally accepted that the loss of all three was directly attributable to gunfire, but the immediate cause of the loss in each case is still, and always will be, shrouded in mystery. It is, of course, known that each one sank in an appallingly short interval of time and that in each case at least a portion of the magazines blew up. The mystery lies in the immediate cause of the magazine explosion. Many different explanations have been advanced, but all of these affect details of design rather than the general characteristics of type. There seems little doubt that one of two things happened: German shell either entered the magazine through penetration of the protective deck, or, having pierced turret or barbette and exploded, flame was communicated to the magazine along the path followed by the ammunition from magazine to gun. From the fact that in the case of the British ships that survived, there was only one case of penetration below the protective deck at any part (no harm resulted from this), it would seem to be highly improbable that the three battle cruisers were all sunk by protective deck penetrations directly over the magazines, and not very probable that any one of them was so sunk. We must not permit our judgment to be swayed too largely by this particularly spectacular phase of the battle. Just as in the case of the battleships previously referred to, the remaining battle cruisers on both sides demonstrated ability of modern ships of large size to withstand heavy punishment without losing their fighting efficiency. The battle cruiser type is essentially and unavoidably less thoroughly protected than the battleship type. This greater vulnerability must result in greater loss of the battle cruiser type, other things being equal; but in the Jutland fight the battle cruisers were engaged much longer and much more severely than the battleships, so that a greater percentage of loss of this type should have resulted even had their protection been equal to that of the battleships. A notable fact in regard to the modern ships, both battleships and battle cruisers, on both sides, is that not a single one experienced a disabling casualty to its machinery, either as a result of damage from enemy fire or as a result of engineering breakdown. In the case of one British ship and one German ship, fires were drawn from under the boilers in one fireroom, due in each case to leakage from adjacent compartments, but in each case this leakage was controlled by the pumping plant

provided for the purpose. Leaving out the three lost battle cruisers, for which no data is available, the dozen large ships in the two fleets which bore the brunt of the punishment were hit a total of about 150 times by large calibre shell, or an average of more than 12 times each. Only one of these dozen ships, namely, the German battle cruiser *Luetzow,* sunk as the result of the damage received. Even this vessel sank only after 6 hours.
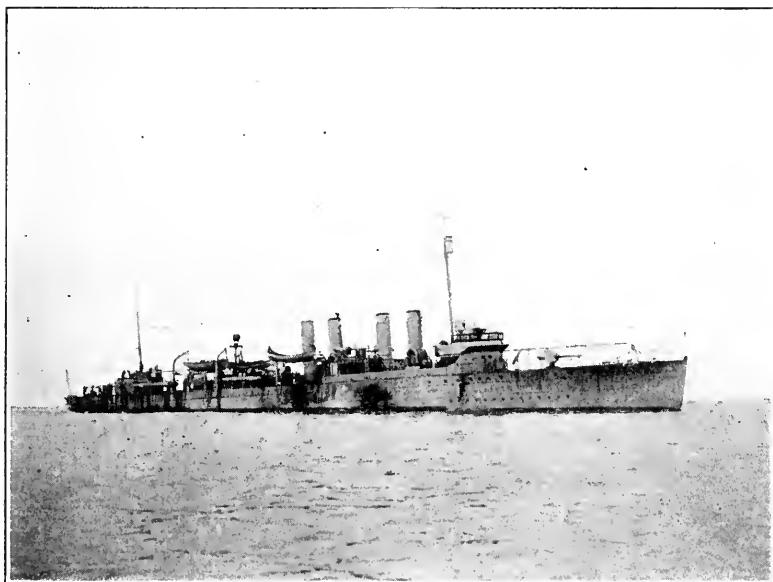
DESTROYERS. 186 CLASS.

Principal characteristics:

Displacement	1215 tons	Speed	35 knots
Length	310 feet	Battery	4-4″ guns
Horsepower	27000	Torpedo tubes	4-21″ triple

She had received 17 large calibre hits and one torpedo. She continued to try to make the best of her way to port, but the struggle was given up about one o'clock in the morning; her crew was taken off by destroyers and she was finally sunk by a friendly torpedo.

The results of the battle, as a test of the defensive qualities of capital ships, show that in the entire action only 4 modern armored ships, all of them of the battle cruiser type, were lost as a result of the action. This was out of a total of 14 engaged and at least 7 out of the remaining 10 survived heavier punishment

than most designers in pre-war days would have considered possible.

Before the war there were two distinct schools of Naval thought in regard to the main armament for the largest fighting ships. This difference of opinion existed internally in probably every navy, but internationally the American and British Navies represented the " Big Gun " advocates, as is shown by the fact that in the former we find successive increases from 12 inch to 14 inch to sixteen inch, and in the latter from 12 inch to 13 and a half inch to fifteen inch. On the other hand, the Germans adhered for a number of years to the 11-inch gun and increased their calibre to 12 inch with apparent reluctance, and a larger calibre did not appear until close to the end of the war. There were undoubtedly excellent theoretical arguments on both sides of this contention. Even now the argument cannot be definitely settled in terms of absolute material results, for too many other factors, which cannot be eliminated, enter into the problem. A convincing answer, however, appears to be provided in the very decided trend of German Naval opinion since the Battle of Jutland. Practically every report from German sources and every German publication bearing on the Battle of Jutland lays stress on the superiority in range and accuracy of the British 15-inch guns. Even if no definite material advantage for the larger calibre gun could be established, here appears to remain a marked moral superiority on the side possessing the biggest guns. This, of course, only confirms the previous views and policies followed in our service.

Summing up, therefore, we find that four outstanding facts of interest to the designer appear to emerge from the smoke and flames of the battle :

First. The value of armor protection.

Second. As a corollary to this, the necessity for the maximum number of major calibre guns; for, if the modern ship can withstand great punishment, we must, for purposes of offence, provide a sufficient number of guns to inflict a degree of punishment which will be fatal.

Third. The tactical value of speed.

Fourth. The futility of subjecting older ships to the attack of modern weapons.

In other words, the value of each one of the three major

elements entering into capital ship design was demonstrated and it cannot be said that any single one has emerged with an importance transcending that of the others. If, however, one must choose among them, the consensus of opinion will probably attach more importance to protection than before the battle. This arises largely from two causes:

1st. The deep impression on the human mind by such an out-
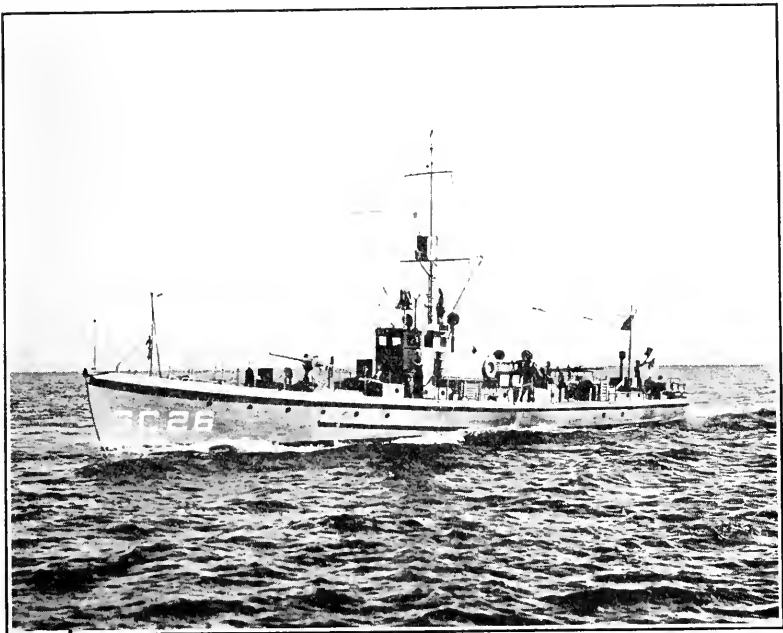
SUBMARINE CHASERS.
Principal characteristics:

Displacement .... 77 tons	Speed ....18 knots
Length........................... 110 feet	Battery ....1-3″ gun
Horsepower.......................660	Depth bomb projector.............1 Y-type

standing tragedy as the almost instantaneous loss of the three great British battle cruisers.

2nd. The impression that German ships, generally speaking, stood punishment better than the English. Admiral Von Tirpitz has been reported to have laid down as the fundamental principle of German design: That vessels before everything else must float; that they must not sink, and if possible, not even list, and that all else is of secondary importance.

This emphasis on the feature of protection is shown already by the intensified and successful efforts of both the British and the American Navies to perfect an efficient form of torpedo protection. In this connection, I think I can safely say that both services have solved this problem so far as the torpedo has been developed to date. It is also interesting to know that during the war the two services frankly and fully compared their solutions of this problem, and that although the solutions differ radically in details, they do not differ much in underlying ideas and both are believed to be successful in result. This emphasis of the protective feature is further shown by the fact that our battle cruisers, whose construction was delayed, due to the necessity for our concentrating on the construction of torpedo craft and merchant vessels during the war, have been re-designed and given much heavier and more complete protection than was originally contemplated, accepting at the same time the slight decrease in speed necessitated thereby. We find precisely the same influence in the case of the latest British battle cruiser, the *Hood,* which was laid down shortly after the battle of Jutland and in which we find more than a 50 per cent. increase in size as compared to their *Renown,* which I have previously referred to, an increase of protection almost to a battleship standard and a decrease in speed.

Turning to the lighter craft used in the Battle of Jutland, it will be found that at several critical times during the engagement both sides used their light cruisers and destroyers to obtain a tactical advantage. Each side likewise used craft of this character to repel the attacks of similar vessels of the enemy. Although the material effect was small, there being probably not more than six torpedo hits on the large vessels of both sides, the necessity for their use is clearly demonstrated not only by their success in obtaining certain tactical advantages, for which they were used, but also in the demonstration that if either Fleet had been without these light craft, the torpedo casualties inflicted on the big ships by the light craft of the side possessing them would have been enormously greater. The losses of light cruisers and destroyers on both sides were heavy in actual number, but not in proportion to the total number engaged, as will be seen from the following table :

	Light Cruisers		Destroyers	
	No. Lost	No. Engaged	No. Lost	No. Engaged
British	0	26	8	78
German	4	11	5	77
Total	4	37	13	155

Submarines played no direct part in this battle, and it is reliably established that neither Fleet was accompanied by submarines, nor were there any submarines even within striking distance of the scene of action.
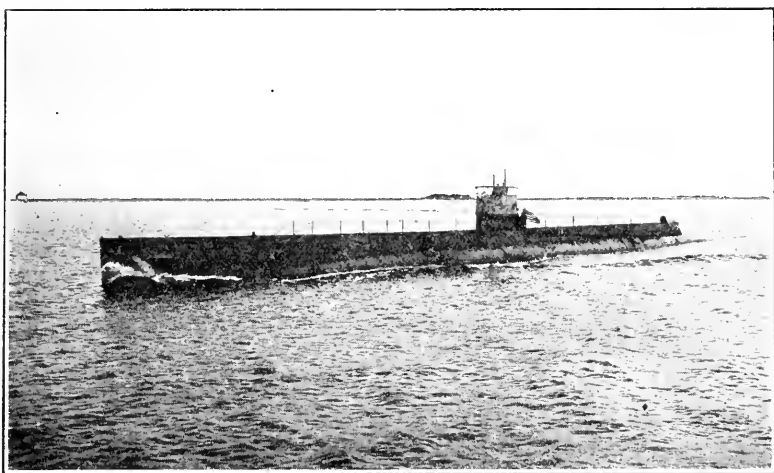
U. S. SUBMARINE A A 1.

Principal characteristics:

Displacement (surface)............1106 tons   Battery..............................1-4″ gun
Length ....269 feet 9 inches   2 Deck torpedo tubes aft.
Horsepower (surface)................. 4400   4 Bow torpedo tubes forward
Speed (surface) ....20 knots

Similarly, aircraft played no part in the action, although it is understood that it was part of the German plan to utilize Zeppelins for scouting purposes in connection with the sortie of the Fleet and that this was only prevented by unfavorable meteorological conditions on the 31st of May. On the following morning, however, German aircraft were out over the North Sea and were undoubtedly of some small assistance to the German Fleet in insuring their safe withdrawal to their harbors.

Passing once more to the general phases of the war, we come

at once to the outstanding feature of the war at sea, the submarine campaign and the methods adopted to combat it. Now that the veil of secrecy has been lifted, we all know how close the German submarine campaign came to being an outstanding factor in the final result. Without entering into the legality and ethics of the German use of the submarine against merchant shipping, which all thoughtful and enlightened men join in condemning, we cannot escape the fact that we must in the future be prepared to find the submarine playing an important part in attacking and throttling enemy commerce, even on their own coasts. This is indicated by the result of the discussion at the Peace Conference when the world at large was so incensed by the barbarous methods used in the German submarine campaign that proposals were seriously put forward to abolish the submarine entirely by international agreement. This proposal, however, was wisely not adopted for, so long as the possibility of war remains, progress of science and engineering and their application to the art of war cannot successfully be throttled unless there is complete unanimity of sentiment throughout the civilized world. The use of submarines during the war has led to placing very great emphasis on the value of radius of action of these vessels, and with radius of action there must go hand in hand improvements in the living conditions on board, so that the physical endurance of the personnel may ˙be sufficiently conserved to permit it to make full use of the material capabilities of the vessel. Both of these elements, even without the usual and concurrent demands for higher speed and greater offensive power, inevitably lead to increased size, except for a limited class of small boats, which, due to a particular strategic situation, such as that occupied by the Germans on the Belgian Coast, makes it possible to use with good results a large number of submarines of small size and limited speed and cruising radius. The technic of mine-laying has, during the war, so kept pace with the strategical and tactical demands for the use of this weapon, that the demonstrated practicability of laying them on the enemy's coast by means of submarines must in the future be taken into account, but this does not affect the general characteristics of the type, as the mine-laying feature can easily be substituted in whole or in part for the torpedo armament. Although the submarine was throughout the war something of a disappointment in the actual results which it obtained

in inflicting loss or damage on the fighting ships of the enemy, its indirect effect on the freedom of action of the main fighting fleets was so considerable that the problem of the development of the so-called fleet submarine is still with us and must be solved largely from theoretical and engineering considerations, rather than from direct experience in action. Another use of the submarine, not largely foreseen, which developed considerable importance during the war, is that of scouting. It has been conclusively demonstrated that these underwater craft form one of the most valuable assets to a navy in obtaining and transmitting information in regard to the movements of the enemy's forces.

War experience developed and emphasized certain facts
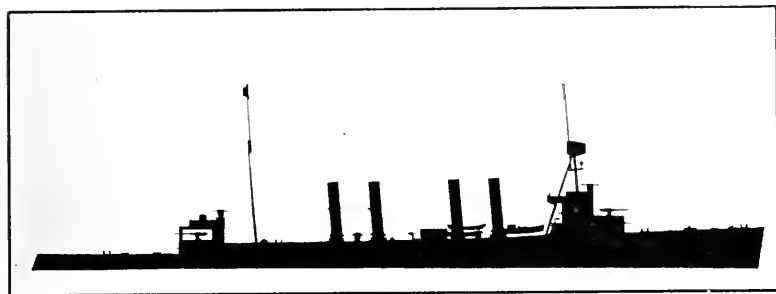
U. S. SCOUT CRUISERS NOS. 4-13.

Principal characteristics:

Displacement	7100 tons	Speed	35 knots
Length	550 feet	Battery	8-6" guns
Horsepower	90000	Torpedo tubes	2-21" submerged

regarding submarines as a type which are very important from the point of view of a designer, and even more important from the point of view of those who have to determine the constitution of a navy. The submarine is essentially an instrument of stealth. Once detected, it must take refuge in the depths where, for any design yet known, its offensive powers become nil, and to the depth charge or explosive bomb developed during the war it is exceedingly vulnerable. In other words, once detected and accurately located, a submarine is at the mercy of a surface vessel. While detection devices, in spite of the enormous effort expended upon them during the war, did not reach perfection, they made much progress and will undoubtedly be steadily improved as time goes on. If we had to-day an accurate device

which would locate a submerged submarine with reasonable ap-
proximation several miles off, and with accuracy when one or two
hundred feet directly under the surface vessel, the submarine
would be already obsolete as a weapon of war. While we may
never reach this ideal, and while the submarine may be given
offensive features to enable it to deal in some fashion with the
surface vessel from beneath the surface, the submarine is essen-
tially a vulnerable, and, if I may so express it, a precarious type;
is necessary to-day and probably will be for many years to come,
but could not be relied upon as the main feature of a navy. We
read at times of proposed submersible battleships and other such
imaginations, but the experience of the war does not seem to
indicate this as a probable future development even if mechani-
cally possible.

On this same subject Sir Eustace d'Eyncourt, the Director of
Naval Construction for the British Admiralty, very recently
stated his views in the course of a paper presented before the
British Institution of Naval Architects. He said:

" A good deal has been written and talked of lately about the
surface Capital Ship being dead and the necessity for submer-
sibles. But with our present knowledge it would be quite impos-
sible to design a submersible ship which on the same displacement
and cost had anything like the fighting qualities on the surface,
which are possessed by the *Hood* (the latest British Battle
Cruiser). Every ship is a compromise, and if in addition to the
ordinary qualities of a battleship, she is required to submerge,
or even partially submerge, a very considerable percentage of
weight has to be added to give her this additional capability of
submergence. She becomes still more of a compromise, and the
added weight must detract from the fighting qualities of the ship
when on the surface, so that whatever is done, other things being
equal, the submersible ship must be inferior to a surface ship
in an ordinary action. There are many difficulties of details in
the design of a submersible battleship which would take too long
to go into fully now, and although there is no doubt that sub-
marines are capable of great development, a little thought will
make it clear to anybody that if naval warfare is to continue, the
surface ship of the line must still hold the field as the principal
fighting unit of any great navy."

Considering types of war vessels existing at the commence-

ment of the war, the position of the Destroyer has been enhanced perhaps more than that of any other, and this has been brought about by our experience in its use against the submarine. As mentioned above, in discussing the results of the Battle of Jutland, the Destroyer has established its indispensability for use with the Fleet, both to attack the enemy and to protect its own capital ships. This use, however, was foreseen and provided for to at least a limited extent in all of the principal navies of the world before the war. It was not, however, foreseen that this type of vessel would be required in undreamed-of numbers to protect the sea lines of communication from the lurking underwater enemy. During the first three years of the war, it had already been found that the destroyer was the most efficient type of vessel
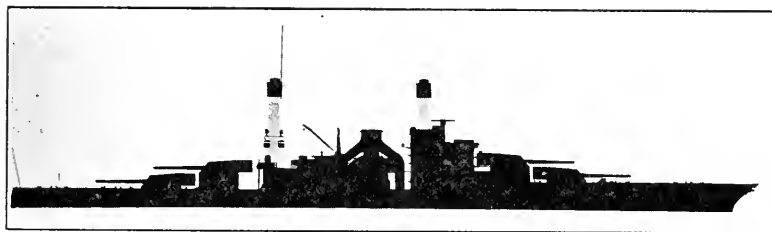
U. S. BATTLE SHIPS NOS. 49-54.

Principal characteristics:

Displacement....................43200 tons	Speed ....23 knots
Length............................ 660 feet	Battery ....12-16″ and 16-6″ guns
Horsepower......................60000	Torpedo tubes ....2-21″ submerged

for hunting down and destroying submarines, and for convoying or protecting a particularly valuable transport or cargo ship. In the spring of 1917, however, the losses of merchant vessels had reached such an alarming rate that the responsible authorities recognized that a new and radical method of protection must be adopted. It was then that the convoy system was put into effect, and soon proved its efficiency to a degree which could hardly have been foretold. It became then imperative that convoy should be provided as nearly as possible for every ship approaching England and France. The only available type of vessel which could perform this very arduous service, requiring many days continuously at sea in all kinds of weather, frequently at very high speed in order to accompany high speed transports, was the destroyer. This demand placed a tremendous strain on the resources of the

Allies in this type of vessel, and it is now a historic fact that the
United States Fleet was stripped of its destroyers which were
sent to the war zone to perform this service, and that British
destroyers were detached from the combined British and American
Battle Fleets, upon which we depended to maintain our command
of the seas, until that Fleet was actually seriously inferior to the
German Fleet in destroyer strength. From our entrance into the
war the United States Navy concentrated upon destroyer build-
ing, its destroyer construction undertaken during the war being
on a scale never before considered possible. It is a matter of
congratulation that this has resulted in our now possessing a fleet,
built or to be completed this year, of more than 300 modern
destroyers of the most efficient type. In regard to the effect of
the war on the characteristics of destroyers, the principal demand
has been in the same direction as in the case of submarines,
namely, for greater cruising radius and increased shelter and
comfort for the personnel. Whereas, during the greater portion
of the time of actual hostilities, convoy was provided for trans-
ports and cargo vessels only in the so-called Submarine Zone,
extending 300 to 400 miles off the European Coast, it had become
evident before the Armistice that as soon as we had sufficient
destroyers for the purpose, escort would have to be provided,
at least for the most important groups of vessels, entirely across
the Atlantic. This was brought about by the ever-increasing
tendency of the German submarines to operate farther afield and
by the approach to completion of a very large type of cruiser
submarine, which it had been known for some time was under
construction in Germany in considerable numbers. The later
United States destroyers would have been prepared to cope with
such submarines, as the size of their guns had been increased
from 4 inches to 5 inches. To obtain these increased qualities
without considerably increasing the size of the boats, which was
of course undesirable under the emergency demand for quantity
production, meant the acceptance of a small decrease in speed.
This we could accept with equanimity as our destroyers were
already somewhat superior in speed to the latest types of corre-
sponding size abroad.

    The necessities of the anti-submarine campaign brought about
new uses for several existing types of vessels, and the development
of several new types. It had always been contemplated that fish-

ing trawlers, drifters and other small vessels of similar type could
be used in time of war as mine sweepers and tenders. With the
development of the depth charge, a bomb containing about 300
pounds of high explosive with a detonating mechanism, which
functioned only when it had sunk to a certain predetermined
depth below the surface of the water, it became evident that any
small type of vessel possessing the necessary seagoing qualities
could be usefully employed against the submarine. As a conse-
quence, this became the principal use to which these small fishing
boats were put during the last year and a half of the war. They
could not, of course, perform the high seas functions of the
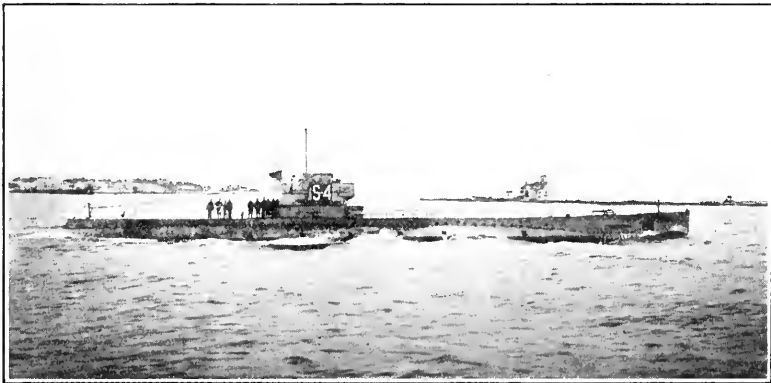
U. S. SUBMARINE S 4.

Principal characteristics:

Displacement (surface)............ ...876 tons	Speed (surface)............ .... .15 knots
Length ....231 feet	Battery......... .. ..1-4″ gun
Horsepower (surface) 1400	4 Bow torpedo tubes

destroyer, but they proved most efficient for hunting operations
and for coastal convoy purposes. The esteem in which they
were held is shown by the fact that in the summer of 1917 the
British Navy put in hand a construction program of more than
500 of these little craft. The limitations on the use of the fishing
boats and the limitations on the production of the destroyer, due
to its large size and cost, resulted in the development of inter-
mediate types which would give good seagoing qualities combined
with a speed comparable to the surface speed of the submarines
themselves, and at the same time sufficiently small and simple
in construction to permit of their production in large numbers.

The British patrol boats and the United States Eagle boats are the principal examples of this type. The latter is really a small destroyer of 200 feet in length and 600 tons' displacement, having a good cruising radius and a speed of 18 knots and carrying an armament of two 4-inch guns with unusually good command and a large number of depth charges, together with the various devices for dropping or throwing these bombs. The British also developed and turned out a considerable number of a somewhat larger type, which were known as " Sloops," which were given a slower speed but a larger cruising radius, together with a more robust type of construction and special features to insure their buoyancy in case of damage by torpedo. All during the war, as previously referred to, the best scientific talent, both in this country and abroad, was making every endeavor to perfect devices which would permit a vessel on the surface to hear a submarine moving below the surface. Various types of these so-called listening gears were developed and some attained a sufficient degree of success to exercise a considerable influence on the development of types of vessels from which they could be used with the maximum of efficiency. It was in fact the development of these devices in America which led to the laying down of our Eagle boats, and the machinery of these boats was designed with especial view to quick starting and stopping, so that internal noises should not in any way effect the use of the listening devices. Even before our actual entry into the war, it had become evident that it would be necessary for us to produce, in the minimum of time, the maximum number of vessels of every type which could be utilized against the submarine. This led to the planning of our program of sub-chasers. Earlier in the war, the British had purchased in this country over 500 gasoline-driven wooden hull boats of 85 feet in length for general coastal use. Their experience indicated that there was a distinct field of utility for vessels of this class, but that they should be of a somewhat larger size with better sea-keeping qualities. In order, therefore, to profit by their experience and at the same time to utilize the considerable resources in this country for the construction of small wooden hull vessels, resources which were not required in the accomplishment of any of the various other war programs, we undertook the construction, immediately upon entering the war, of 350 of these sub-chasers, each 110 feet in length, about 75 tons displacement, and having

three 200-horsepower gasoline engines, giving a top speed of about 16 knots. They were fitted with special facilities for the use of various types of listening gear. They carried one small gun and a number of depth charges. In their seagoing qualities, these boats more than met the anticipations of their designers. About 200 of them crossed the Atlantic under their own power and performed most useful service in the Mediterranean Sea and on the French and English Coasts. However, these boats must be regarded as stopgaps rather than a type to be found in large numbers in a permanent navy.
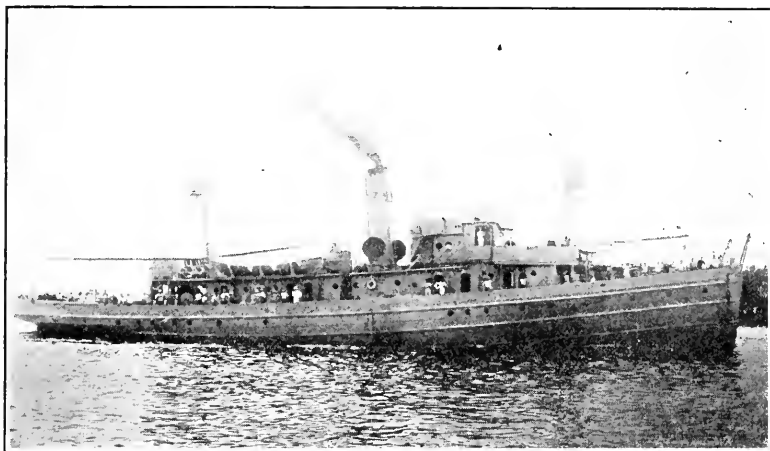
MINE SWEEPERS.

Principal characteristics:

Displacement	950 tons	Speed	14 knots
Length	180 feet	Battery	2-3″ A A guns
Horsepower	1400		

Another class of operations which resulted in the development of a new type, or rather the resurrection with new features of an old type, was the Naval Operations against shore fortifications. When the Germans had occupied the Belgian Coast, it became evident that the Navy must be prepared to undertake operations against that coast, unless the Germans were to be permitted to remain in undisturbed possession, allowing them an extremely undesirable freedom of action by using the ports as bases for submarines and destroyer activities. To meet this condition and the possibility of similar conditions arising elsewhere in the vast theatre of the war, the British very early put in hand a number

of modernized monitors, which repeated the well-known charac-
teristics of the early American vessels of this class; that is, slow
speed, the heaviest guns, armor protection, low freeboard, and
small size, but added to these a modern and efficient form of
torpedo protection; the last named really forms the *sine qua non*
of the modern monitor, for it must of necessity operate off hostile
coasts and by its slow speed is peculiarly liable to successful attack
by submarines. These monitors at intervals throughout the war
carried out a series of very interesting bombardments on the
Belgian Coast, which were accompanied by the use of such mod-
ern methods as spotting by means of aircraft and protection by
means of smoke screens, produced by small fast boats accompany-
ing them. In general, however, these operations failed to produce
any decisive results, and this experience, combined with that
gained through the attempts by older British and French battle-
ships to reduce the fortifications at the Dardanelles, has gone far
to confirm the opinion held prior to the war that ships cannot
compete successfully with shore fortifications.

Although not productive of new types, and not, strictly
speaking, exercising any influence on naval types, it is not possible
to pass over the development of the transport service during the
war, as its operations were on such an enormous scale. The
British conveyed to and fro from the various theatres of war a
total of something like 13,000,000 men, but the great bulk of these
was for the short distance across the Channel. The most im-
pressive undertakings were the combination of the American
and British resources, with some help from the other Allies, in
transporting to Europe nearly 2,000,000 men during the war,
and the bringing of them home in a period of a little over six
months by the American Navy with some help from foreign
sources. The enormous undertakings demonstrated that the
great passenger vessels used commercially in time of peace can
be quickly and efficiently converted for use as transports, and
that, therefore, the naval designer need in the future only provide
for the intelligent utilization of the great mass of experience
accumulated in fitting merchant vessels for this purpose. As an
example of the progress made in this direction in the course of
the war, can be cited the fact that when some of the large passen-
ger vessels were first fitted for use as transports, it was thought
that they had been given the maximum troop capacity. After

some months of experience, however, it was possible so to modify and perfect the arrangements that their capacity was increased in some cases as much as 50 per cent.

In reviewing the use of existing novel types during the war, one cannot omit reference to the active and important part played by certain types of auxiliaries. Colliers, tankers and supply ships were used to an enormous extent, but these are of such a purely merchant type that they require no especial note, except to remark that the few Colliers we had built as naval auxiliaries, with special handling appliances showed up exceptionally well. The purely naval types which demonstrated their efficiency and value were
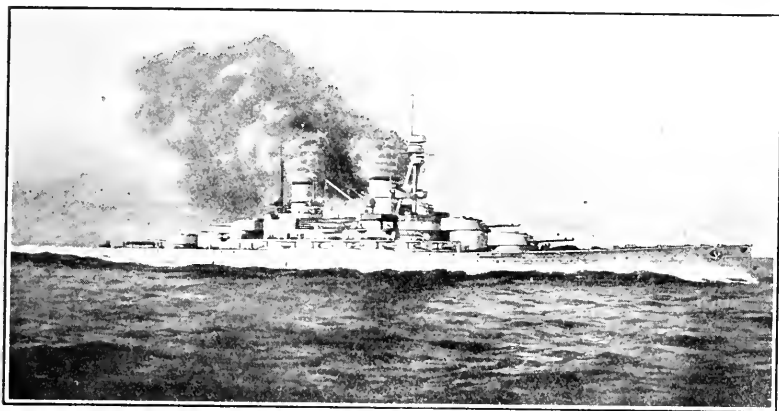
GERMAN BATTLE-CRUISER *DERFFLINGER*.

Displacement....................26180 tons	Speed ....26.5 knots
Length ....689 feet	Battery ....8-12″ and 14-5.9″ guns
Horsepower.....................63000	Submerged torpedo tubes...........4-19.7″

the destroyer and submarine tenders and repair ships. One or more of these vessels were stationed at each one of our principal operating bases abroad, and without them our destroyer and submarine forces would have been unable to maintain their great efficiency and high percentage of time employed in active service. Due to the shortage of shipping, it was not possible to fit out and supply an unlimited number of vessels of this type, and it soon became evident that each existing unit must be utilized to its highest degree of productivity. This led to the erection on shore at the principal bases of barracks for housing the shop operating forces, so that the ships themselves could be run 24 hours a day, using three shifts of mechanics. This development leads to

the belief that in the future in certain types of operation we may be led to provide special barrack ships for carrying and berthing sufficient personnel to utilize to the full the repair facilities provided on the vessels specially fitted for that purpose.

I have previously referred briefly to the development of the new and large type of naval vessel called an aircraft carrier. In the very early stages of the war, attempts were made to attack the principal naval bases in Germany by means of aircraft, but it was found that neither the aircraft themselves nor the commercial vessels hastily fitted up for the purpose of carrying them were sufficiently developed to permit of success in such an undertaking. I cannot in this paper take up in detail the wonderful development in aircraft during the course of the war, but the technical development resulting in increased size and speed and carrying capacity are well known. These were quickly taken advantage of by naval designers to fit them for such purely naval purposes as scouting, fire control of the heavy guns of big ships, torpedo carrying and launching, etc.

The actual offensive use of aircraft against naval vessels was little developed during the war. Perhaps the most prominent case was that of the *Goeben* which was ashore near the Dardanelles, and for six days exposed to aircraft attack, it being stated that some 217 bombs were dropped against her. There is no doubt that there will be a great development of aircraft for naval use as a result of the war experience, and some enthusiasts have visions of navies of the air rendering obsolete the navies of the ocean.

The United States Navy, which has in its own hands the development and control of its aircraft for use over the water, should take the lead in any air naval development; but there is no doubt that, step by step with the air offensive, there will be developed a defensive. The defensive, moreover, will not be passive. We have seen in the late war how the light craft, destroyers, etc., on one side met and countered the attacks of similar craft on the other side. Had either side been deprived of its light craft, it would have been at a most serious disadvantage. Similarly, developments in the air will undoubtedly be along the line of defending the capital ship by auxiliary and offensive aircraft. The big ship which must be protected from projectiles of a ton weight falling at angles of 30 degrees, fired from ships

almost out of sight below the horizon, is not yet in serious danger
from bombs carried by present-day aircraft, with chances of hit-
ting small indeed.

At the moment it appears that the torpedo plane is the most
promising development; its weapon of attack is the torpedo
which the capital ship must already be prepared to defend itself
from, whether fired by a surface vessel or a submarine. A tor-
pedo from a ship in the air is no more deadly than from a subma-
rine under the surface. It seems probable that aircraft will sooner
become dangerous to destroyers and the light vessels generally
than to the large ships of the line. The former are more vulner-
able and will be less able to protect themselves.

Even these early developments of naval uses for aircraft made
it evident that they could not efficiently perform such functions
with the fleet unless they could be carried with the fleet, not only
on long cruises but actually in battle, with the result that special
types of ships have appeared to fill this requirement. The first
essential of this type is that it should be capable not only of
launching aeroplanes but also of receiving them back after the
accomplishment of their mission. With the present development
of aeroplanes and seaplanes, the only practicable method of pro-
viding the latter requirement is the provision of an enormously
large and absolutely clear deck upon which the planes can light and
be brought to rest. The next requirement is that such a vessel
shall have a speed sufficient to permit it to keep up with the main
battle fleet when it is going into action. This means a speed of
20 to 25 knots. These qualities, together with the need for suffi-
cient space to house and care for a considerable number of planes,
together with their personnel, has resulted in vessels of 10,000
to 25,000 tons displacement. To obtain a clear upper deck re-
quires special arrangements for funnels, navigating bridges, etc.,
which has resulted in the only absolutely new type of naval ves-
sels of large size and cost which has appeared as a result of
the war experience.

At the other extreme among new types appearing as a result
of the war, comes what have been termed coastal motor boats.
These appeared more as a result of possibilities presented by mod-
ern engineering developments than as a result of the need for
filling a specific naval requirement. The perfection of the gaso-
line motor led in the years before the war to the construction,

for sporting purposes, of very light high-speed small boats. Due
to the fact that they were developed primarily for racing, they
were suitable for use only in comparatively smooth water and
had to be handled with extreme care. A study of their possi-
bilities by British designers, supported by the enthusiasm of
young naval officers, resulted in the production of boats of 40 to
70 feet in length and capable of speeds from 35 to 45 knots an
hour, each carrying from one to three modern torpedoes, and with
the hulls constructed on such scientific principles that they could
go to sea in comparatively rough weather, and could be hoisted
on board light cruisers or other types of naval vessels. These
little boats performed splendid service off the Belgian Coast, and
the tale of their operations forms one of the most exciting chap-
ters in modern naval annals. But the most spectacular, and at
the same time valuable service performed by boats of this type
during the war, was the daring penetration by the Italians into a
fortified Austrian harbor where they sank a battleship lying at
anchor. Later, in operations against the Bolshevists, a small
British flotilla penetrated to the inner harbor of Kronstadt, where
they succeeded in sinking two battleships and two other large
vessels.

I have several times, in the course of this paper, referred to
the results experienced when war vessels of older types are sub-
jected to attack by modern weapons. During the war there were
sunk by hostile action 21 pre-Dreadnaught battleships and 27
armored cruisers; of this total of 48, 11 were sunk by gunfire and
37 by mine or torpedo, only a single explosion in nearly every
case being necessary to inflict the fatal damage. It is only neces-
sary to refer briefly to such incidents as the sinking of the British
battleship *Formidable*, the three cruisers *Cressy*, *Boukir* and
Hogue, the loss of four old battleships at the Dardanelles, the
sinking of the *Gneisau* and *Scharnhorst* off the Falkland Islands,
the loss of the British *Hampshire*, and the American cruiser
San Diego as the result of striking a single mine, together with
numerous other incidents of similar nature, to show that such
vessels as these, most of which were commissioned within ten
years immediately preceding the war, are totally incapable of
withstanding the terrific effects of present-day gunfire and torpedo
attack. This showing is particularly impressive when compared
to the demonstrated ability, as discussed above, of the most

modern vessels to survive severe and repeated attacks. These
qualities of resistance and defense can only be provided on vessels
of large dimensions and displacement. The necessity for retiring
these older types was well demonstrated by the fact that except
for a few used for special purposes, both the British and the
Germans had placed most of their older capital ships out of com-
mission before the war had run its course.

To sum up, therefore, the experience of the war, so far as it
can be grasped to date, has resulted in demands in the case of
every existing type of war vessel which can only be met by in-
creased size and cost. It has resulted in the introduction of only
one new type of major importance, namely, the Aircraft Carrier,
but it has introduced a number of small types which will probably
survive but will not be constructed in large numbers in times of
peace, as they are peculiarly adaptable to being produced quickly
in large numbers after the emergency of war has arrived.

Although we must conclude that the present tendency is
toward increased size and cost, one cannot overlook the fact
that this very tendency, under the present financial, economic and
political conditions in the world, may actually result in the long
run in the disappearance from future building programs of these
very types and the substitution for them of smaller and cheaper
units made possible by new developments in science and engineer-
ing. To meet this condition there never was more need than
at the present time of vision and imagination on the part of the
fighting forces afloat and the naval designers ashore, for that
nation which can develop the weapons which will render obsolete
the present great ships and can substitute for them a smaller and
cheaper unit capable of defeating them will win in the new
era the command of the seas, which this war has shown is so
all important to ultimate victory.

Potash Deposits of Alsace. (*U. S. Geological Survey, Press
Bulletin No. 445.*)—Potash salts were discovered in upper Alsace,
in 1904, in drilling for oil. Subsequent explorations and develop-
ments indicate that the deposits underlie an area of more than 70
square miles, and that the workable beds have a depth of about 2000
feet and range in thickness from 6 to 30 feet. The salts consist
essentially of sylvinite, a mixture of sylvite and rock salt. Esti-
mates place the quantity of potash salts in the deposit at 1,472,-
058,000 metric tons, which gives more than 300,000,000 tons of

potash (K_2O). The first mining shaft was completed in 1909 and production began in 1910. In 1913, 40,707 tons of potash (K_2O) was produced from this source. The German Kali Syndicate, which controlled these mines as well as those at Stassfurt, determined the proportion of potash to be produced by the Alsatian mines at about 4 per cent. of the total annual production from Germany. The main object in limiting the output was to prevent overproduction and thus a lowering of the price.

When the Armistice was signed in November, 1918, the Alsatian mines were transferred to French control and apparently were in a very bad state of repair.

On the Nature of the Heat Production in a System of Platinum Black, Alcohol, and Air. L. B. LOEB. (*Proc. National Academy of Sciences,* March, 1920.)—When a little platinum black is put into a volume of air saturated with vapor of either ethyl or methyl alcohol much heat is developed and the solid becomes incandescent. Two theories have been advanced at different times to account for this: (*a*) That it is due to the liberation of heat resulting from the adsorption; (*b*) that it is to be ascribed to the development of heat at the surface of the platinum black caused by the oxidation of the alcohol vapor.

A thermal couple was covered with platinum black. When it was put into an atmosphere of alcohol vapor and carbon dioxide, where no oxidation could take place, the temperature rose 0.36° C., due to adsorption. When the experiment was repeated with air substituted for carbon dioxide, there was a rise of 34°, almost one hundred times as much. Furthermore, the heat due to adsorption is soon all set free, while the heat development due to oxidation continues as long as alcohol and oxygen are present.

G. F. S.

Peat as a Gas Producer. (*U. S. Geological Survey, Press Bulletin No. 446.*)—Peat consumed in a properly designed gas producer yields gas of good quality and in abundant quantity in comparison with the yield from coal and also many valuable by-products. This is perhaps the most effective utilization of peat fuel for generating heat and power, because peat that is to be used in this way does not need to be so carefully prepared nor so thoroughly dried as peat that is to be consumed for domestic purposes or under steam boilers. Gas-producing plants using peat fuel are operated in England, Ireland, Germany, Sweden, Italy, and Russia, but in the United States, although experiments have been made, no gas-producing plants are operated with peat.

Automatic Telephony. (*Electrician,* March 26, 1920.)—The British Post Office has for the present ceased to develop the automatic telephone system.

THE NITROGEN INDUSTRY.*

BY

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NITROGEN, itself, is an inert gas of no particular use, but nitrogenous compounds are necessary to agriculture, to refrigeration, to munitions manufacture, and to the application of chemistry in general. In the native gaseous state, it makes up about four-fifths of the atmosphere, and combined it occurs as nitrate minerals, as organic compounds, and in carboniferous deposits. Atmospheric nitrogen is of use only after it has been artificially compounded or " fixed," a preposition which the natural inertness of nitrogen renders difficult and expensive. It has five general habits of combination—that with oxygen, giving rise to nitric acid and its retinue of nitrate salts; that with hydrogen giving ammonia and the ammonium salts; that with carbon, to form cyanogen and the cyanides; that with basic elements yielding nitrides; and, organically, in the form of organic ammoniates. The only mineral deposits of consequence are those comprising the nitrate fields of northern Chile. The organic resources include all kinds of animal and vegetable refuse. Coal-tar ammonia from retort-coke and gas manufacture, along with some shale-oil ammonia, makes up practically the whole supply derived from the carboniferous sources. This range of associations, including animal, vegetable, mineral, and atmospheric sources, surpasses all established rules of resource occurrence.

The utilization of the nitrogen contained in the air is an old problem. Cavendish discovered in 1781 that by burning hydrogen in a surplus of air, water was formed which reacted nitrically. Prominent chemists such as Lavoisier, Priestley, Davy, Robert Bunsen, Boettger, and others all gave constant time and study to the same phenomena. Boettger determined the formation of nitric acid in the discharge of an electric current. In 1900 an experimental plant was erected at Niagara by two American

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* Communicated by Dr. Allerton S. Cushman.

inventors, C. S. Bradley and D. R. Lovejoy, in order to burn
nitrogen from the air into nitric acid by a very high electric
current. The plant soon proved unremunerative and was aban-
doned. In 1903, the Norwegians, Birkeland and Eyde, started
in Norway the new industry of producing nitric acid from the
air by means of a luminous arc. This same arc process was shortly
afterwards started in Austria and Italy. In 1906 the calcium
cyanamid process was successfully established in Italy, and in
the subsequent years preceding the war was installed in Ger-
many, Norway, France, Switzerland, America, Austria, Japan,
and Sweden. The third of the established methods of fixing
nitrogen, the Haber process for the synthesis of ammonia,
was brought to a successful commercial stage in Germany
in 1913.

The form of nitrogenous compound is of secondary import-
ance, since this may be modified more or less readily to suit the
need, but its value is conditioned in terms of its availability in the
form of nitrogen compounds. The several sources are classified
industrially under three heads:

(1) Nitrogen occurring naturally in the form of market-
able compounds.

(2) Nitrogen rendered available incidentally in the course
of operations otherwise directed.

(3) Nitrogen whose availability is dependent on special fixa-
tion treatment.

Chile nitrate is the outstanding representative of the first
class. The guano industry, or what there is left of it, and a few
other odds and ends of production from organic sources belong
here as well, but their combined output is so relatively small, that
the Chilean industry comprises what amounts to a monopoly of
the natural resources. It is not operated as such, however, but
by private capital, which owns and operates the nitrate fields, pay-
ing the Chilean government a royalty or export tax amounting
to about $11.20 per ton. Chile derives over 60 per cent. of its
total yearly revenue from the export tax on Chile nitrate. British
and Chilean interests share about equally in making up the far
greater part of the capital invested. The balance is largely Ger-
man and American. The total capitalization in 1909 amounted to
approximately $134,000,000, representing an actual valuation of
about $30,000,000. Various efforts on the part of commercial

interests involved to effect combinations for the purpose of sta-
bilizing production have been attempted, but have not been en-
tirely successful, and the general tendency has all along been
towards overproduction.

Before the war, practically the whole of the world's require-
ments in respect to nitrate and nitric nitrogen were met by the
exportation of nitrate of soda from Chile, and the price of the
product has hitherto governed the market price of combined
nitrogen. The Chilean nitrate industry is one of long standing
and has been characterized by a steady rate of expansion. By
the middle of the nineteenth century the exports had attained a
figure of about 100,000 tons per annum, whereas the shipments
from Chile in the year prior to the war (1913) amounted to over
2,400,000 tons, 70 per cent. to 80 per cent. of which was accounted
for by the requirements of Germany (833,112 tons), the United
States (589,187 tons), France (327,192 tons), and Belgium
(318,515 tons) alone. From 1870 to 1917 Chile has produced
55,800,000 tons of saltpeter. Experts, such as Adolf Frank and
Birkeland, do not believe that this supply can last for more than
thirty to forty years.

The Chilean nitrate fields lie in the arid valley basin to the
east of the lofty coast range and just south of the present
Peruvian boundary line. They do not occur as a single ex-
pansive area of deposition, but as deposits scattered here and there
along the desert land at the bases of the mountain slopes. The
formation consists of a conglomerate or breccia of rock material
from the adjacent slopes, cemented with a mixture of soluble
salts in which sodium chloride is the dominant member with
sodium nitrate ranking second. This formation, called caliche,
lies for the most part just below the surface of the ground and
varies from a few feet to many feet in thickness. Only in scat-
tered patches is the caliche high enough in content of sodium
nitrate to warrant treatment. These patches are sought out and
excavated, and the picked ore is loaded into carts which haul it
to the extraction plant for treatment. Here the soluble salts as
a whole, are extracted in solution, and the nitrate in turn is
segregated from the other salts by crystallization. Aside from
haulage, hand labor is used throughout.

Due to the crude operations used in treating the caliche, the
cost of production is correspondingly high, amounting to around

$25 to $30 per ton at seaboard, inclusive of the $11 export tax. The caliche regarded as worth treating contains not less than 10 per cent. sodium nitrate and ranges up to 25 per cent. and over, with an average of about 18 per cent. The product marketed is of two general grades, the ordinary listed as 95 per cent. nitrate, and the refined, a guaranteed 96 per cent. nitrate low in sodium chloride. The nitrate is marketed largely through commission houses. The American situation is mostly in the hands of three companies, W. R. Grace and Company, E. I. du Pont de Nemours Powder Company, and Wessel, Duval and Company.

To the class of by-product compounds belong, with the few exceptions noted above, the nitrogenous products of organic derivation as a whole, and those from carboniferous sources such as coal and oil shale. From the former source comes a mass of organic refuse resulting from activities dealing with animal, vegetable, and fish products, and carrying nitrogen in the form of organic ammoniates, commonly left as such for use in agriculture. From the latter, the nitrogen recovered is all chemical nitrogen in the form of ammonia and ammonium salts, mostly ammonium sulphate, and is available in all capacities.

The organic production is impossible of definite analysis from any angle. The lack of systematically compiled records and back of that the miscellaneous largely decentralized character of the output, along with the fact that the producing costs are for the most part, indistinguishable, leaves altogether too much to the imagination. Much of the supply is derived from connections of sanitation, especially of local sanitation, such as the rural practice for which there is no measure whatever. Another big source of supply is from tankage, the refuse from animal rendering plants. Also the issue is lost here in the scattering of the production, the indefiniteness of composition, and the fact that not all of the product is used as a source of nitrogen, some of it going into the preparation of animal food. The same is true of cotton-seed meal and various other less prominent forms of organic waste resulting from industrial activities. Fish-scrap and slaughter-house refuse from meat packing also contribute prominently and at the same time rather more definitely to the supply of agricultural nitrogen. Even here adequate figures are not available.

Aside from the conversion of organic ammoniates, which is practiced on a large scale only in a few instances, notably that of

the Paris system of sewage disposal, four general types of indus-
trial operation figure more or less in the production of by-product
ammonia. They include coal distillation, bone carbonization, oil-
shale distillation, and blast-furnace operations. The American
production, however, is all derived from the first two types.
Both the others are active producers abroad, especially in Scot-
land, but neither of them has as yet obtained a foothold in this
country. The American recovery in connection with bone car-
bonization is of minor consequence. Practically the whole supply
comes from gas works and by-product coking operations.

The growth of ammonia production from by-product coke
has been extremely rapid in this country and is still on the in-
crease. The enlargement of by-product coke production is shown
by the following table, which includes solely the coke industry
and not coke from gas works, etc.:

	1918—Per cent.	1919—Per cent.
By-product	44	54
Bee-hive	56	46

The installation of the by-product coke process means a larger
supply not only of ammonia but also of benzol, toluol, phenol,
naphthalene, and other products absolutely essential for muni-
tions purposes and required in time of peace for the dye-stuffs
industry. The use of the by-product coke process also means
the production of large quantities of gas for power purposes.
If the destructive distillation of coal is conducted in special
producer-gas ovens, the output of ammonia can be increased
five to six fold and power comparable with hydroelectric power
can be obtained at the same time.

That bituminous coal used should be treated in by-product
ovens is recognized the world over. It is becoming increasingly
practicable to do this, and the use of coke for domestic purposes,
as well as for the production of iron and steel, is rapidly increas-
ing. The general use of coke instead of coal throughout a country
does away with the smoke nuisance and all of its accompanying
loss to property, and if such were the conditions in this country,
it would produce, besides other by-products, approximately
1,000,000 tons of ammonia alone. The day is far off before this
highly desirable result will be reached, but it should none the less
be striven for.

The organic nitrogen recovered in all of the various by-product connections taken together probably constitutes 40 per cent. to 50 per cent. of the total supply. Coal-product ammonia in this country adds another 12 per cent. to 15 per cent. Therefore, over half of our supply is of by-product derivation. The domestic output of the United States is supplemented in the case of the organic form by considerable importations from South America, and, until interfered with by the war, small amounts of ammonium sulphate were imported annually from Europe. Essentially, however, the by-product supply is of domestic origin.

The industrial output of this country is built up as a sequence to industrial concentration. This is evidenced all down the line, especially in the output of coke-oven ammonia from the steel industry, and in that of organic ammoniates from the meat-packing industry. It is this influence of coördinated industrial concentration, along with the call for the major operations, that controls the supply of by-product nitrogen. Therefore, the development and handling of the industrial output comes naturally to be largely in the hands of trade combinations. Thus, the coal-product ammonia situation is largely at the disposal of the Barrett Company, the tankage and other animal product ammoniates gather for disposal at the hands of the packing interests, and the nitrogenous fertilizers from cotton seed are for the most part prepared and marketed by interests subsidiary to the Cotton Oil Company.

The manufacturing interests of this country which are involved are concerned primarily in the manufacture of other than nitrogen products. The by-product nitrogen recovered has to compete for its market against what comes from the other two sources of supply, and its price goes just low enough to enable it to do so. The limits set in the incidental character of the output leave no special incentive to carry the price competition further. Whatever additional latitude of advantage as to cost of production it possesses goes not to promoting a further reduction in the price of nitrogen but to lowering costs with reference to the major item of production. Gas-house ammonia, for example, does not affect the nitrogen market so much as it does the cost of gas, and the organic ammoniates recovered in connection with meat packing have not lowered fertilizer costs so much as they have kept down the cost of meat to the consumer.

Thus, the by-product class of supply, though the leading one in the point of magnitude, and by far the cheapest to produce, has little to do with determining the price of nitrogen. The selling price of by-product nitrogen is determined by the price the product from competing sources brings. In this country, it is controlled by the price of Chile nitrate, and not, as commonly imputed, by the trade combinations that develop and handle the output.

The arc fixation process was the first commercial process to be developed for the fixation of nitrogen. It is installed in southern Norway, employing 250,000 kilowatts of electricity developed from the cheapest large installation of hydroelectric power in the world. This is the only large installation of the arc process, but small installations of an experimental nature have been put up in other countries.

In the arc process, nitric acid is produced by the direct combination of the oxygen and the nitrogen of the air to form a dilute gaseous mixture of nitric oxides with air. The nitric oxide is converted into nitric dioxide, and is absorbed in water in immense granite towers to form nitric acid. The method is one of the most inefficient known as regards production in relation to power consumed. Nevertheless, on account of the very cheap horsepower available in Norway—$2 to $5 per horsepower year—and the fact that the raw materials cost nothing and are always at hand, nitric acid can there be produced by the arc process at a cost less than by any other commercial process.

Efforts to introduce the arc process outside of Norway have resulted unsatisfactorily, and it has made relatively little headway. The reason for this is two-fold. So far, its use of power has proven uneconomical, and its product unsatisfactory. The former of these two objections depends on its force on the demand for power, but the latter is more decisive. The immediate end product is nitric acid, which is a 30 per cent. to 35 per cent. acid, as against 50 per cent. to 55 per cent. acid obtained by other processes, and is both difficult to transport and limited as to use. To be put in shape for agricultural use it must be neutralized in the form of a nitrate salt. Limestone is the only cheap neutralizing agent. This gives a salt, calcium nitrate, which absorbs moisture, cakes, and is thus unsuited for agricultural uses in many countries. The Nitrogen Products Company, a small plant near Tacoma, Washington, working on off-peak power at $10

per horsepower year, aims to overcome this difficulty of an un-
suitable fertilizer by turning out its arc product in the form of
sodium nitrite.

By the Haber process, nitrogen from the air and hydrogen
obtained from water are directly combined to form ammonia
under the influence of a catalyzer. The production and purifica-
tion of the hydrogen made by the reducing action of either coal or
iron upon steam involves one of the chief items of cost in this
process. The fact that the combination of nitrogen and hydrogen
takes place at temperatures about 500° C. and at pressures of 100
to 200 atmospheres involves some danger and many other techni-
cal difficulties which have been overcome in Germany by the
Badische Company, which owns the Haber plants and process.
The technical control of the Haber process is of very great im-
portance and requires a high degree of training and skill. This
process was first commercially installed in Germany in 1913 with
a plant capacity of 7500 tons of ammonia or 30,000 tons of
ammonium sulphate, and in 1918 the output by this process
was 265,000 tons of ammonia or 1,060,000 tons of am-
monium sulphate.

As installed in the Haber plant at Appau, Germany, the hy-
drogen is obtained from water-gas manufacture. The average
percentage composition of the gas by volume is: hydrogen, 49
per cent.; carbon monoxide, 43 per cent.; nitrogen, 5 per cent.;
and carbon dioxide, 3 per cent. The proportion of nitrogen is
increased by mixing in the generator gas of the following com-
position: Nitrogen, 63 per cent.; carbon monoxide, 24 per cent.;
hydrogen, 6 per cent.; carbon dioxide, 5 per cent; and methane,
2 per cent. The carbon monoxide in the gas is converted to car-
bon dioxide and at the same time a further supply of hydrogen
is added by mixing the gas with steam at a temperature of 400°
to 500° C. in the presence of a catalyst, which is principally iron
oxide with a very small percentage of other oxides, such as
chronium oxide. The reaction is:

$$CO + H_2O = CO_2 + H_2 + 10 \text{ calories}$$
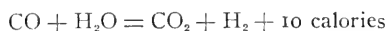
A slight excess of steam is required, but too great an excess must
be avoided to prevent lowering of the temperature. The carbon
dioxide in the gas is now eliminated by compression at 20 kg.

per sq. cm. in contact with water. Any residual carbon monoxide
or dioxide remaining after this treatment is eliminated by cop-
per formate or copper chloride under a pressure of 200 kg. per
sq. cm. The proportion of nitrogen to hydrogen is kept below
1 to 3 until just before reaching the ammonia catalyst. Then
the required amount is added from a liquid air machine. Methane
is not a poison for ammonia catalysts but practically all the other
hydocarbons are. The synthesis takes place in autoclaves at a
temperature of 400° to 600° C. and at a pressure of about 200
atmospheres. At the start of the operation 2 per cent. to 6 per
cent. of oxygen is added and the action begun by an electric spark.
The gas after catalysis contains about 6 per cent. ammonia. This
ammonia is absorbed by water, a 20 per cent. solution being ob-
tained. The unconverted nitrogen and hydrogen are returned to
the autoclaves for repetition of the cycle. The actual yield is
70 per cent. to 90 per cent. of the calculated.

The ammonia produced by the Haber process is in a water-
free liquid condition ready for immediate oxidation without
purification. Reliable information from Germany indicates that
pure anhydrous ammonia can be produced in liquid condition for
about four cents per pound. It is the cheapest process for the
production of synthetic ammonia, and has the lowest power re-
quirement of any of the nitrogen fixation processes, as shown by
the following table:

Fixation Process	K W Hours—Per KG. of Nitrogen Fixed
Arc process	73.7
Calcium cyanamid process	16.5–19.5
Haber process	3.6
Hausser process	8.9
Serpek process	10.0–12.0

Another great advantage of this process is that its product is
easily available for transportation and for fertilizer.

An adaptation (lower pressures) of the Haber process to
American conditions was worked out by the General Chemical
Company, and a plant with a rated capacity of 60,000 pounds of
anhydrous ammonia per day was projected at Sheffield, Alabama,
at the instance of the Government. The plant was completed, but
before it could be tuned up for actual production the war ended.

The cyanamid process has been developed in many parts of
Europe, but in the western hemisphere only at Niagara Falls,

Ontario, Canada. It requires cheap power for its successful operation and has obtained its greatest development owing to the fact that it requires only about one-fifth the horsepower per ton of fixed nitrogen per year that is required by the arc process. The Niagara Falls plant is now operating under a special contract with the Canadian government by which it is able to obtain power at the rate of $12 per horsepower year. This plant draws heavily on power in the preparation of the necessary carbide, and it is not believed that this plant will be able to continue operations upon the expiration of its present contract with the Canadian government as it will not be able to renew same at so low a figure.

The cyanamid process involves: First, the production of calcium carbide in a large electric furnace from lime and coke or anthracite coal; and second, the fine grinding of this calcium carbide out of contact with air, and the heating of a portion of the ground mass to a red heat to start the absorption of the nitrogen which is then added, as long as it is taken up by the carbide, to form cyanamid. The cyanamid is in turn ground and given a special treatment to remove acetylene gas in order to avoid explosions later. The cyanamid, mixed with sodium carbonate and lime, is then treated with steam in large autoclaves to convert the nitrogen of the cyanamid into ammonia gas. The process involves a number of steps and is somewhat complicated:

$$CaO + 3C = CaC_2 + CO$$
$$CaC_2 + N_2 = CaCN_2 + C$$
$$CaCN_2 + 3H_2O = 2NH_3 + CaCO_3$$
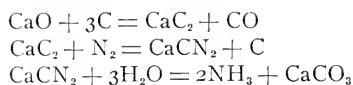
Under the stress of the wartime demand for nitrogen, this Government contracted for the erection of three plants, one at Muscle Shoals, Ala., one near Toledo, Ohio, and one near Cincinnati, Ohio, with a total rated capacity amounting to 220,000 tons of ammonium nitrate per year. The work on all three plants was well under way, but none had reached the producing stage at the time of the signing of the armistice.

The cyanide process of fixation is being experimented with, but has not been developed commercially. Nitrogen in passing through a red-hot mixture of finely divided sodium carbonate, coke, and iron, reacts with the sodium and carbon to give sodium cyanide. The reaction takes place readily. The sodium car-

bonate can be recovered to be used over again, and the iron can also be repeatedly used in the process.

The Government erected a small plant with a rated daily capacity of ten tons of sodium cyanide at Saltville, Virginia, and it had just reached the producing stage when the armistice was signed. The cyanide process, as installed in this plant, was divided into three stages: (1) the mechanical preparation of the material treated in the retorts; (2) the treatment of the briquetted soda ash-iron-coke mixture with nitrogen at 1000° C.; and (3) the extracting of the cyanide as sodium cyanide from the cyanized briquettes produced in the preceding stage of the process. The barren briquettes, after recovery of the cyanide, were returned to the mechanical preparation building, where they were reground, brought back to their original composition, and remade. The cost of making cyanide at this plant, as operated with its military personnel and post organization, was roughly 20 cents per pound, which price included all charges except royalties and profits. However, this cost would have been materially lowered by constant operation at capacity.

The only process of any prominence aiming to fix nitrogen in the nitride form is one developed by the Aluminum Company of America. This has for its working principle the fact that a mixture of alumina and carbon highly heated will absorb nitrogen by reacting to give aluminum nitride. The nitride, when heated with caustic soda, gives its end product in the form of pure ammonia. The greatest difficulty encountered in applying this process commercially seems to be that of providing a furnace capable of standing the temperature requirements. This process has not succeeded in making good industrially.

Atmospheric nitrogen and oxygen combine to a limited extent when the gases are heated to a sufficiently high temperature, and the Hausser process relies upon the explosion of a combustible gas and air, with or without enriching oxygen, in a closed vessel for bringing about the combination. The exhaust gases from the explosion apparatus contain a small percentage of oxides of nitrogen, which are recovered in the form of dilute nitric acid by absorption in water. This process has been only partly developed and is still being experimented with.

The combustion processes have a close analogy with the Hausser process, the aim in each case being to effect the oxidation of

atmospheric nitrogen by direct thermal action. The methods, of which those proposed by Bender are the best known, involve the combustion of fuel gases, such as coal gas, water gas, or natural methane gas, under conditions whereby the temperature is notably augmented, the products of combustion being rapidly cooled in order to conserve, as far as possible, the small percentage of nitric oxide that is formed. The latter is recovered in the form of dilute nitric acid, as in the case of the arc process. Combustion processes present some attractions, owing to the comparative simplicity and inexpensive character of the plant required, and if successfully developed would have an important bearing upon nitrogen fixation in countries possessing abundant supplies of coal.

All processes for the synthetic production of nitric acid, except the arc, Hausser, and combustion processes, involve the oxidation of ammonia. The processes commercially in use involve the direct oxidation of ammonia gas in the presence of air in contact with metallic platinum. By the oxidation of ammonia, nitric oxide gases are obtained of much higher concentration than those produced by the arc and similar processes. Accordingly, much less tower space is necessary for their absorption and much stronger acids can be directly obtained by concentration. An acid of 50 per cent. to 55 per cent. strength is easily obtained directly from the towers, and the concentration therof is a simple matter.

The Frank Caro process, used in Germany, involves passing mixtures of ammonia and air through electrically-heated platinum nets of 80 to 100 mesh. The platinum is heated to a dull red heat and serves as a catalytic agent under whose influence the ammonia, instead of burning to nitrogen and water, as normally would be the case, causes the nitrogen to form nitric oxide.

In the Kaiser process, also used in Germany, the air is heated before its mixture with the ammonia, and under these conditions no electric heating of the platinum net is necessary.

The Landis process passes the gas downward through the net instead of upward, as in the Frank Caro process, and cools the gases before they are allowed to come in contact with the net, instead of heating them, as is done in the Kaiser process.

The details of the preparation of the catalyzer used in the Ostwald-Barton process are kept secret, but it is known to have a very small cross-section and is placed at the end of a 60 mm.

tube, so that the products of combustion passing through the tube heat the mixed ammonia and air by radiation as they approach the catalyzer.   By this means no external heat is necessary.   The reaction when once started continues without interruption for weeks.   It is simply necessary, by means of blowers, to force the mixture of ammonia and air through the catalyzer.

The process developed by the General Chemical Company in collaboration with the U. S. Bureau of Mines takes advantage of the fact that the action is exothermic.   In this modified process no outside heat whatsoever is required after the action is once started.

A general idea of the relationship of the non-synthetic and synthetic processes from the point of view of the manufacture of particular nitrogenous products is afforded by the following table, which summarizes the primary and secondary products obtainable by the various methods of recovering or fixing nitrogen. Although everyone of these processes is capable of yielding a solid nitrogenous fertilizer, such as ammonium sulphate, calcium cyanamid, or a nitrate, either as a primary or as a secondary product, it is important to note that, of the nitrogen fixation processes, only one, namely, the calcium cyanamid process, yields a fertilizer directly as a primary product.

NITROGEN RECOVERY AND FIXATION PROCESSES.

Primary and Secondary Products.

Processes.	Primary Products.	Secondary Products.
Recovery Processes:		
By - product ammonia processes.	Crude ammonia liquor or ammonium sulphate (according to system of recovery adopted).	Other ammonium salts.
Retort or Chile nitrate processes.	Nitric acid-dilute (65 per cent.) or concentrated (90–96 per cent.), according to method of operation.	Nitrates, such as ammonium nitrate.
Fixation Processes:		
Arc process.	Oxides of nitrogen normally recovered as dilute (30–40 per cent.) nitric acid.	Concentrated (93–95 per cent.) nitric acid, or nitrates such as ammonium or calcium

Processes.	Primary Products.	Secondary Products.
Calcium cyanamid process.	Calcium cyanamid.	nitrate. Ammonia or ammonium sulphate, nitrate of urea, guanidine, and other organic products.
Haber process.	Ammonia liquor.	Ammonium sulphate or other ammonium salts.
Cyanide processes.	Crude sodium, barium, or other metallic cyanides.	Finished cyanides, or ammonia, or ammonium sulphate.
Hausser and Bender processes.	Oxides of nitrogen, normally recovered as dilute (30 per cent.) nitric acid.	Concentrated (93–96 per cent.) nitric acid, or nitrates such as ammonium or calcium nitrate.
Serpek process.	Crude or pure aluminum nitride.	Ammonia liquor or ammonium sulphate.

Conversion Process:

Ammonia oxidation process.	Oxides of nitrogen, normally recovered as dilute (50–53 per cent.) nitric acid or alternatively as metallic nitrates.	Concentrated (93–96 per cent.) nitric acid or nitrates such as ammonium or calcium sulphate.

At the present time there is no significant production of synthetic nitrates in Japan, although it is known that the Japanese chemical industry is interested in the question and that it is undergoing rapid development comparable to our own. There are several small cyanamid plants in Japan, but their production is not large. Japanese interests are believed to be contemplating the erection of a plant or plants to produce synthetic nitrates using the process of the General Chemical Company or something similar.

In England, Brunner Mond and Company, Ltd., operating the Solvay soda plants in that country, have arranged to take over the incomplete Haber plant started by the government, and will operate the Haber process in addition to their ammonia soda business. Great Britain is at present taking vigorous steps to establish domestic fixed nitrogen industries, according to plans providing for a production in excess of domestic peace requirements.

Much interest is being aroused in France in the production

of synthetic nitrogenous products. The new processes of M. G. Claude are being tested with great success at experimental works near Montereau. He has succeeded in applying pressures of 1000 atmospheres and more in the synthetic production of ammonia. Hitherto this has been done only in Germany, but M. Claude has surpassed the German scientists, in that under the new conditions the combination of hydrogen and nitrogen takes place with such intensity that a very small apparatus is capable of a considerable output. Whereas one can get only 0.33 grams of ammonia per catalytic gram by the Haber process, M. Claude gets 10 grams.

Patent rights for the Haber process in France have been acquired by the firm Kuhlmann in conjunction with the Colliery companies at Lens and the Banque de Paris. The construction of large factories for the production of synthetic ammonia, nitric acid, etc., is about to be taken in hand, and the capital to be invested in these undertakings will amount to fifty million francs.

Italy has several cyanamid plants with a total production, however, insufficient to meet the domestic demand. Like Great Britain and France, it is putting forth every effort to increase its fixed nitrogen industries.

The total possible yearly output from existing plants in Germany is estimated at 500,000 tons of nitrogen, 60 per cent. of which can be produced by the Haber-Bosch process and 20 per cent. each by the cyanamid works and the gas and coke industries. In October, 1918, the industry had so far recovered that 25,000 tons of nitrogen were being delivered per month when further progress was interrupted by the revolution. The 18 per cent. of the total nitrogen supplies contributed by gas works before the war has now sunk to 5 per cent., but these will continue to manufacture ammonium sulphate in order to make full use of their plants. The demand for artificial nitrogenous fertilizers in Germany is very great, since all farmers there are now convinced of their importance and value. With the coöperation of the government, the five leading producers of nitrogenous fertilizers have formed a syndicate, the object of which is not to make large profits, but to increase output, to exercise control over prices, and to secure fair distribution. Attached to this syndicate is a committee on which both producers and consumers are represented. By mutual concessions and adjustments between these it is be-

lieved that the German farmer will be able to obtain his nitrogenous fertilizers three times cheaper than if he imported them from abroad.

During the past six months the nitrate exports from Chile have dropped considerably, due chiefly to labor strikes and the unsettled conditions in that country. The government is yet undecided as to what stand to take as regards this industry; that is, whether to lower the export tax on Chile nitrate, from which it receives its principal revenue, and thereby give its nitrate a better chance of competing with the synthetic nitrate on the market from Germany, principally, and other countries, or to maintain the high export tax and take a chance on being able to keep its sales of Chile nitrate fairly large in the face of competition of foreign synthetic nitrates.

If the Kahn bill, now pending in Congress, is passed, the U. S. Army contemplates running its cyanamid plant at Muscle Shoals, Alabama, and is at present engaged in considerable research work in connection with the various products obtainable. This plant is designed for a yearly output of 220,000 tons of cyanamid or 35,000 tons of ammonia. The original cost of this plant was $70,000,000 and $12,000,000 are yet needed, $2,000,000 for necessary repairs and alterations, and $10,000,000 as an operating fund. The Army authorities plan to run one-third of the plant, four furnaces, at a profit on the money still to be invested ($12,000,000). Three of the four furnaces are to be used in making ammonium sulphate, and the fourth in mixed compounds. They also hope to be able to separate out and recover the 15 per cent. graphite and 6 per cent. sodium hydroxide contained in the autoclave smudge. In the way of fertilizers, they are at present experimenting with compounds of ammonium sulphate and ammonium nitrate, and an excellent non-hygroscopic compound consisting of sodium chloride, potassium chloride, and ammonium nitrate.

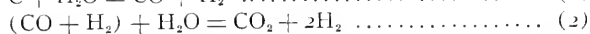The formation of the Atmospheric Nitrogen Corporation, capitalized at $5,000,000, and combining the Solvay Process Company with the General Chemical Company in the matter of nitrogen fixation, has just been announced. This new corporation plans to operate the Haber process in this country in connection with its soda industry. As the establishment of an independent, self-supporting fixed nitrogen industry in America for

the increase of crops in time of peace and as a preparedness measure for war is greatly to be desired, this announcement is of extreme economic importance.

In the Haber process, the chief item of expense is the cost and purification of the hydrogen required for the reaction:

$$N_2 + 3H_2 = 2NH_3$$
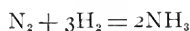
The cheapest known method of producing hydrogen in quantity for this process and the one used at Appau is shown by the reactions:

$$C + H_2O = CO + H_2 \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$
$$(CO + H_2) + H_2O = CO_2 + 2H_2 \quad \dots\dots\dots\dots\dots\dots\dots (2)$$

Eleven tons of carbon dioxide are produced for every ton of hydrogen set free. For a long time this carbon dioxide was considered as a useless waste product, and such appears to have been the case in Germany until early in 1918. Someone, however, finally remembered that in the Solvay soda process thousands of tons of carbon dioxide are used each year and many hundred thousand tons of limestone burned for this specific purpose. A short study at once made plain that the ammonia industry and the soda industry for most civilized countries is or should be of the same order of magnitude, and a further interesting interdependence was at once brought out.

The Solvay soda process is usually considered as involving the following reactions:

$$CaCO_3 + C (+ O_2) = CaO + 2CO_2 \quad \dots\dots\dots\dots\dots\dots (3)$$
$$NaCl + H_2O + CO_2 + NH_3 = NaHCO_3 + NH_4Cl \dots (4)$$
$$2NaHCO_3 = Na_2CO_3 + CO_2 + H_2O \quad \dots\dots\dots\dots\dots\dots (5)$$
$$2NH_4Cl + CaO = CaCl_2 + 2NH_3 + H_2O \quad \dots\dots\dots\dots (6)$$
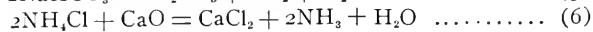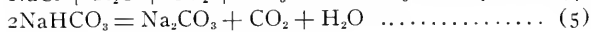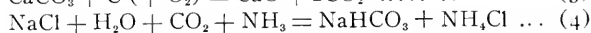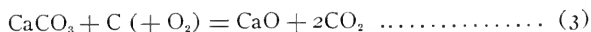
By adding the rich carbon dioxide from (5) to the much leaner gas from (3), a carbon dioxide of around 55 per cent. carbon dioxide is obtained for use in (4). The waste carbon dioxide from the Haber process is much purer and varies from about 75 per cent., if nitrogen is mixed with the water gas, to approximately 90 per cent. if it is not. One of the great drawbacks of the Solvay process is the waste of ammonia in recovery (6), and of lime and chlorine, as calcium chloride, the latter being a waste nuisance that is present at every ammonia soda plant. At the same time, one of the problems of any plant fixing nitrogen

as ammonia is to produce the ammonia in a form suitable for application to the soil. This is commonly done by neutralizing with sulphuric acid to form the sulphate. Any neutral, fixed, and nonhygroscopic salt of ammonia, of which there are few, would probably do as well. It has been shown by Georges Ville and others that ammonium chloride, which is a more concentrated nitrogen product than the sulphate and meets the other requirements also, is equal to sulphate as a fertilizer.

Accordingly, a synthetic ammonia plant and a Solvay soda plant supplement each other perfectly when the above method of producing hydrogen is utilized. If the waste carbon dioxide, together with the ammonia, is passed into brine, the products obtained at once are sodium bicarbonate and ammonium chloride, the one ready for sale or conversion into soda ash, the second ready for the fertilizer markets. For the recovery of ammonium chloride in the solid form, suitable for fertilizers, it seems that it will not be necessary to resort to evaporation, for Claude states that in collaboration with Mittau he has worked out an adaptation of the method of Schreib for alternative precipitation of the sodium bicarbonate and of the ammonium chloride, depending upon the very slight solubility of the ammonium chloride in cold solutions of neutral ammonium carbonate of appropriate concentration.

By the coördination of these two processes to meet America's needs for fixed nitrogen, there will result lower installation costs for both processes, the saving of several hundred thousand tons of sulphuric acid, several hundred thousand tons of lime, several thousand tons of coke, and the elimination of a waste product that has always been considered a nuisance. The saving may be credited to either product at will.

One wartime achievement, the oxidation of ammonia, stands out as affording a worth that is unmistakably clear. The nitrogen situation has two aspects, the military and the agricultural. The military focus is on nitric acid, and the readiest means of affording a supply, while the agricultural focus is on ammonium compounds, or their equivalent in neutral nitrogen salts, and the most economical means of supply. Here is the parting of the ways to expediency. Ammonia oxidation gives a means of supplying the military requirement from the direct line of agricultural efficiency. From the strictly military viewpoint, it has the

objection of being a roundabout procedure. The direct line of military efficiency, however, has no peace-time function, and consequently cannot be maintained in time of peace in trim for war, but must, instead, be built up expressly to meet wartime exigencies. We have had one illustration of what this means in the way of time and money, and this one ought to suffice. The agricultural channel once built upon a basis of economic efficiency is open at all times. It is then only required to keep an eye on the emergency needs in the way of oxidation equipment, a very easy matter. Therefore, instead of the uncertain procedure of trusting to luck which characterized our prewar attitude toward nitrogen on the one hand, or of attempting the impossible in the way of maintaining a military program of industrial procedure in time of peace on the other, all that is needed is a constructive program devoted expressly to the interests of economic efficiency.

At present there is no import duty on nitrogen and there probably will not be any, for nitrogen is an important cog in the mechanism of food supply, and the peace-time emphasis is primarily on cheapness and only secondarily on the point of origin. Accordingly, looking ahead, the American market conditions, once world trade is fully restored, are due to reflect the world conditions. The sudden ending of the war with its consequent calling off of the military requirement, which had been building up steadily since even before the outbreak of hostilities in 1914, left the world with a producing capacity 30 per cent. to 40 per cent. above normal. This apparent overproduction, amounting to some half million tons of nitrogen, is, however, not proving real, due chiefly to the great food shortage. On the other hand, there is the producing capacity of the plants not yet in operation to be taken into consideration. Whatever may be the capacity of agriculture to absorb from the total production, it is not believed that it will take up the full amount immediately or without special inducement. The inference follows that price and production will come down to stimulate and coördinate with the increase in demand. At any rate, there will no doubt be a contest of competition between the three types of industrial source, the natural, the by-product, and the fixation types.

With the development of fixation, there have been a lot of unfounded statements to the effect that the day of Chile nitrate is passing. However, the high cost of producing Chile nitrate

(around $30 a ton) is largely due to the unsystematized and crude methods of operations, the high export tax, and overcapital-ization, all of which are variable factors and are susceptible of indefinite modification in keeping with the need. Chile nitrate has never made any pretense of competing against by-product nitrogen with its advantages in the way of low incidental produc-ing costs and proximity to the market. The discrepancy between the by-product supply and the total demand for nitrogen has all along comprised the field of opportunity opening to Chile nitrate. In this, its only noteworthy competitor, is the fix-ation industry.

The fixation sources are impossible of analysis on a definite basis of cost, as there are too many variable factors involved. Repeated attempts have been made, but all they have served to bring out is that under certain conditions, as for instance, of power supply, and for certain express purposes one form of project has an apparent margin of advantage over another, and *vice versa* for other conditions. In some cases the solution ad-vanced has called for some special measure of relief from indus-trial competition, whether natural, as in the case of the Scandinavian power supply, or political, as in the case of the American and German projects. Fixation, however, has its pos-sibilities of development into something commercially and economically as well as politically worth while, but the existing condition of affairs is undoubtedly due for a lot of boiling down, and much that is useless is certainly due to go. The American developments have a particularly unfavorable economic setting in the prevailing scale of costs.

With reference to the organic group of compounds, the outlook for the future is as uncertain as the actual conditions of to-day. The centralized development of meat packing, of animal-rendering establishments, and of cotton ginning have given rise in their time to highly important recoveries of nitrog-enous waste, but with the forward progress of developments, this usage in turn is giving way to a more advanced order. Cot-ton-seed as a fertilizer is giving place to a cotton-seed product industry; tankage as a fertilizer is giving place to the artificial compounding of animal food; and the horse, an important con-tributor of agricultural nitrogen in times past, is giving way to the automobile. Developments are on foot that lead in both

directions, and there is no telling how the balance is due to shift. Probably the best guess is that relatively at least it will be downward rather than upward.

The outlook for by-product ammonia is more definite. Ammonia is the end point of material refinement, so here the nitrogen developments hold all they get rather than going on to lose out again in a further refinement of usage as in the case of the organic group. The output has increased consistently and rapidly, owing to the transition from bee-hive to by-product coking operations, and to the progress of centralization and coördination, in other words, with reference to coke manufacture.

In general, the by-product sources are of an order such that they were not materially affected one way or the other by the war, and consequently are not being materially affected in the process of readjustment. Of special significance in connection with what lies on beyond for the by-production of nitrogen is its relationship to the progress of industrial coördination.

So far, the recovery of by-products in connection with the use of coal has been confined in the one direction of coke-making, along with the analogous procedure of gas manufacture. The development which has thus started in the coke industry will, however, not stop there. The loss of motion resulting from lack of coördination in the use of coal is just as great in other directions as in that of coke-making, and the advantages of integral usage may be expected to assert themselves. Already projects are being put through, such as furnishing gas to cities, employing by-product operations located at the mines in support of the waning natural gas supply, and integrated heat, light and power projects operating on coal with by-product recovery. Meanwhile, the motor-fuel situation is suggestive of interesting developments ahead. There is every reason to believe that the petroleum resources cannot continue to meet the growing demand; in fact, that the occasion for support is already at hand. Whatever the nature of these supporting developments, whether they take the form of a shale-oil industry or what, it seems certain they will usher in an important source of by-product nitrogen.

Germany can produce nitrates at one-half the cost of nitrates in this country which are manufactured from the imported Chilean product, and consequently, the German farmer can be supplied with fertilizers, manufactured from synthetic nitrates, at one-half

the cost to the American farmer. This advantage to Germany is, of course, stupendous. If Germany succeeds in monopolizing this industry, which she is in a position to do, barring internal disorders and revolutions, she can export nitrates at a price which will enable her to supply her farmers with fertilizers at practically no cost, or she can undercut the price of nitrogenous products to such a point that it will no longer be profitable for Chile to operate her nitrate mines. If these mines are ever abandoned, it will take years to reëstablish the normal production. If this happens, and our Government is so short-sighted as to permit a German monopoly of the nitrate industry, Germany will also indirectly control the world's production of explosives and propellants. Our fleet and army will, of course, be utterly helpless without nitrates necessary for munitions of war.

Synthetic nitrate plants should be constructed, and their success will grant assurance of our safety in times of war, and in times of peace will provide the American farmer with fertilizers at almost one-half their present cost. In event of war, our existence may be dependent upon such plants. In any event, our security would be vastly increased, the burden of obligation carried by our fleet would be greatly reduced, and its functional, effective value doubled.

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The Mass-spectra of Chemical Elements. F. W. Aston.
(*Phil. Mag.*, May, 1920.)—The Positive Ray Spectrograph is de-
scribed in detail by means of which a focussed spectrum is ob-
tained. The lines due to the joint action of a magnetic and of an
electric field are located in positions which depend only on the
ratio of mass to electrical charge. The following elements have
been analyzed: H, He, C, N, O, Ne, Cl, A, Kr, X, Hg. Of these
the first five seem to be pure, while the others are apparently made
up of isotopes, varying in number from two in the case of argon
to six for krypton. With the exception of hydrogen " all masses
measured, allowing for multiple charges, are exactly whole num-
bers within the error of experiment (o = 16)." While there is no
reason to doubt the accuracy of the measurements, it is possible
to interpret them in a somewhat different manner, as, indeed, a
Philadelphia investigator does in the case of the atomic weight of
argon. The prevalence of whole numbers is a fact of great sig-
nificance for the understanding of the structure of the atom. To
explain the failure of hydrogen to have a whole number for its
mass, its mass proving by measurement to be 1.008, the author
reminds us that, on the electromagnetic theory of mass, the mass
of an aggregate of masses is not in general equal to the sum of
the component masses except when these are relatively far apart.
In the nucleus of oxygen the packing of particles and electrons is
close. Hence the atomic mass of the latter element is not sixteen
times as great as that of hydrogen, but a little less than sixteen.
                                                           G. F. S.

New Process for Preparation of Glycerol.—During war glyc-
erol is required in abnormally large quantities for the manufac-
ture of munitions. Since fats and oils are the source of glycerol
the supply of these foodstuffs is consequently decreased; for the
fatty acids, which may be obtained as a by-product in the manu-
facture of glycerol, cannot be directly ingested and assimilated.

However, Arthur Lapworth and Leonore K. Pearson, of the University of Manchester, England, have devised a method for the chemical decomposition of fats with the production of glycerol and an edible by-product—the mannitol esters of the fatty acids, which are synthetic fats and oils. This research is described in the *Biochemical Journal,* 1919, xiii, 296–300. Olein, such as olive oil or stearin, is mixed with mannitol and a small amount of dry sodium ethoxide which functions as a catalyst. The mixture is distilled under reduced pressure. The distillate consists of glycerol, water, and a small amount of alcohol. The residue in the distillation vessel is a substance which possesses many of the properties of the original fat; in chemical compositions it corresponds closely to a mixture of the dioleates or distearates of mannitan and isomannide. The maximum yield of glycerol is obtained when fat and mannitol are mixed in the ratio of two molecules of the former and three molecules of the latter.

J. S. H.

Paracoumarone Resin in Varnishes.—This resin is obtained by the polymerization of the coumarone and indene in certain aromatic naphthas, and is recovered in considerable quantities as a by-product in the manufacture of these naphthas. W. W. KING, F. W. BAYARD, and F. H. RHODES (*Journal of Industrial and Engineering Chemistry,* 1920, xii, 549–552) point out the advantages of paracoumarone resin as a varnish gum. The price of the resin is approximately equal to that of ester gum and much below that of the better grades of kauri and other imported gums. The resin may be purchased in quantity in a number of grades, which differ in color and in melting point. Since it is free from dirt and sticks, neither the resin nor the varnish require purification to remove such impurities. The resin contains no volatile ingredients which are lost during the cooking of the varnish; therefore, all the resin remains in the varnish. Since the resin is chemically inert, varnish made with it is very resistant to the action of ammonia, lye, soap, other alkalies, vinegar, fruit acids, other acids, alcohol, and alcoholic solutions.

J. S. H.

On the Relation Between Illumination and Electrical Conductivity in Selenium. A. O. RANKINE. (*Phil. Mag.,* May, 1920.)— The investigator gives a surprisingly good character to selenium cells for reliability within definite limits. " The effect of light on them is quantitatively reproducible again and again."

Contrary to the tacitly accepted idea that the change of electrical conductivity in selenium is as the square root of the intensity of the incident light it is claimed that extended experiments show the change to be proportional to the fourth root of the light intensity.   G. F. S.

GRAVITATION AND RELATIVITY.*

BY

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THERE are two classes of theories relative to gravitation: those relating to the manner of action of gravitation without regard to its cause, and those relating to the cause of gravitation. There have been many theories of both classes. Until recent years the classic Newton theory of the manner of action was accepted as complete and correct, and most theories dealt with the cause. In the consideration of the fundamental phenomena of physics the conception of a cause is not always clear. We are accustomed to explaining the more complex phenomena, let us say those of geology, for example, in terms of other simpler phenomena, chemical changes and effects of heat and mechanical forces, which while simpler are still tangible, directly perceptible phenomena. But when we attempt to find causes for these phenomena in turn, we find our conception of the meaning of the word " cause " is not always clear; for we can not indefinitely explain each thing in terms of another. In the past, when physicists attempted to find a cause for gravitation or for some other fundamental phenomenon, they were apt to suppose it produced by some mechanism or process which resembled ordinary things, and which seemed simpler merely because it was more familiar. Thus gravitational forces were thought to be produced by the impact of flying particles or by currents or waves in a material medium, while the systems thus imagined were fully as complex as gravitational action, if not more so, and required an explanation for themselves that was no easier to give than the first.

The more recent observations have rendered improbable the existence of any material medium or ether in the old meaning of the word, in space, by showing that phenomena are independent of the velocity of the system with its observer through space. The only thing remaining that might be considered simpler or more fundamental than gravitation is electricity, and it is pos-

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* Communicated by the Author.

sible that gravitation and electrical phenomena are correlated phenomena, forming part of the same system, rather than that one is entirely a function of the other. Any attempt to explain such things in terms of something still more fundamental carries us into an entirely different sphere of thought, in which our ideas of cause must be reconsidered.

It will thus be seen that the majority of the older theories of the cause of gravitation are no longer worth serious consideration, and only those intended to correlate gravitation with electricity are of consequence. Even in these there has been little real success, as is indicated by the fact that no one has been able to deduce the value of the constant of gravitation from any theoretical considerations.

GRAVITATION ACCORDING TO NEWTON.

The gravitational theories which are now receiving attention are those relating to the manner of action of gravitation. Newton's theory is such a theory, and before taking up the recent theories it will be well to consider briefly Newton's theory, the evidence from which Newton deduced it, the evidence supporting it that has been obtained since Newton's time, and the reasons why we are not now entirely satisfied with it, but are considering new theories.

The steps by which Newton's law was deduced will be presented by means of a form of diagram which I have found very useful in the study of physical principles. The lines in the diagram indicate upon what antecedent principles each principle depends.

A complete account of the principles comprised in this diagram would, of course, include a precise statement of each, with its demonstration or the presentation of observational evidence. This would require too much time to be presented now, and only a résumé is attempted.

Kepler's first law stated that the orbits of planets are ellipses with the sun at a focus. The second stated that the line connecting the sun with a planet passes over equal areas in equal times. The third stated that the square of the period of revolution of a planet is proportional to the cube of the major axis of its orbit.

From Kepler's laws, obtained by the observation of planets, Newton was able to deduce in a rigorous manner that the accele-

ration of a planet is in the direction of the sun and varies as the inverse square of the distance. To express this in terms of force it is necessary to introduce the definition of force, which depends in turn upon that of mass. Newton's definition of mass

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┌──────────────────────┐   ┌──────────────────────┐
│     Measurement      │   │     Measurement      │
│     of length.       │   │      of time.        │
└──────────────────────┘   └──────────────────────┘

┌──────────────────┐  ┌──────────────────┐  ┌──────────────────┐
│ Definition of    │  │ Kepler's first   │  │ Kepler's second  │
│ mass (faulty).   │  │ law Orbits       │  │ law Areas.       │
│                  │  │ ellipses.        │  │                  │
└──────────────────┘  └──────────────────┘  └──────────────────┘

┌──────────────────┐  ┌──────────────────┐  ┌──────────────────┐
│                  │  │ Kepler's third   │  │ Planets          │
│ F = d/dt (mv)    │  │ law              │  │ accelerated      │
│                  │  │ t² = ka³         │  │ toward sun.      │
└──────────────────┘  └──────────────────┘  └──────────────────┘

┌──────────────────┐  ┌──────────────────┐
│ Weight           │  │ Acceleration     │
│ proportional     │  │ varies as        │
│ to mass.         │  │ inverse square   │
│                  │  │ of distance.     │
└──────────────────┘  └──────────────────┘

              ┌──────────────────┐
              │ Force on planet  │
              │ varies as        │
              │ inverse square.  │
              └──────────────────┘

              ┌──────────────────┐
              │ F = C m₁m₂/d'²   │
              │ for all bodies   │
              │ A generalization.│
              └──────────────────┘
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Blocks shown in the diagram:

- Measurement of length.
- Measurement of time.
- Definition of mass (faulty).
- Kepler's first law Orbits ellipses.
- Kepler's second law Areas.
- $F = \dfrac{d}{dt}(mv)$
- Kepler's third law $t^2 = ka^3$
- Planets accelerated toward sun.
- Weight proportional to mass.
- Acceleration varies as inverse square of distance.
- Force on planet varies as inverse square.
- $F = C\dfrac{m_1 m_2}{d'^2}$ for all bodies A generalization.

GRAVITATION ACCORDING TO NEWTON.

was quite insufficient. He defined it as the product of volume and density; but density is commonly defined as the ratio of mass to volume, and as he presented no independent definition of density, he was guilty of reasoning in a circle.

His definition of force involves the assumption that the force

measured by the rate of increase of momentum of a moving object is the same for all velocities. For ordinary velocities this is very nearly true, as can be shown by the observation of falling bodies. Nevertheless, the fact should not be overlooked that the assumption that this is universally true is involved. I will not discuss now in detail the correlation of this definition and Newton's laws of motion, from Newton's point of view, but these matters will be considered later from a more modern standpoint. If, however, we accept the relation, force equals mass times acceleration, which results from the definition of force as the time rate of change of momentum, it follows that the attractive force exerted on a planet by the sun varies inversely as the square of the distance. The proportionality of attractive force or weight to mass, Newton deduced from pendulum observations.

Upon these results Newton based his general law of gravitation, which he held to apply to all bodies in the universe whatever their size, velocity, relative distance or condition. This was a generalization from observations of the behavior of bodies of a limited variety under limited conditions. It was a bold generalization, but one that has been of great value to science, and has stood for a long time as one of the best established of physical principles. We have now to compare it with the more extensive and more accurate observations that have been made since Newton's time; and even if we find that small discrepancies exist, it will still remain preëminent among human accomplishments.
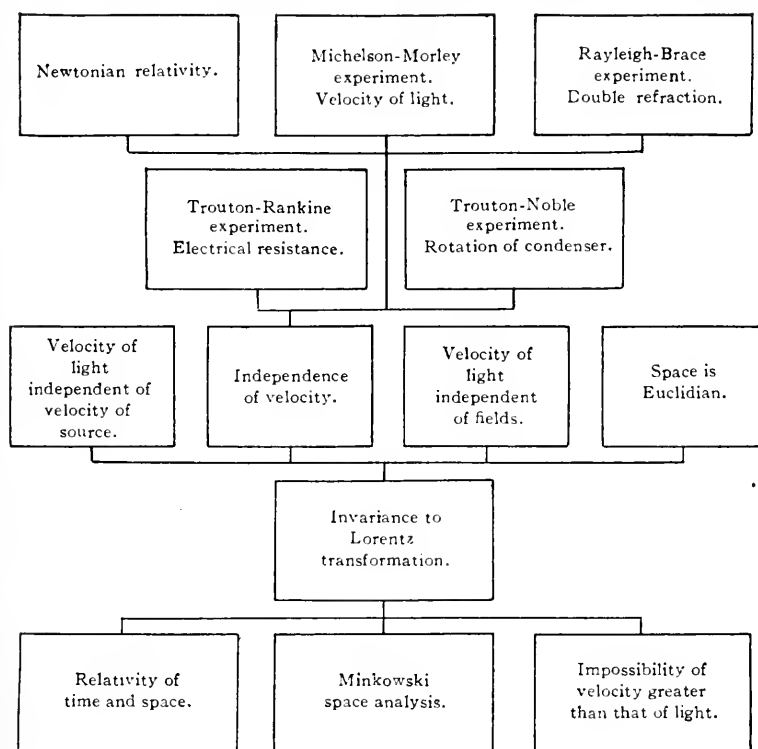
NEWTON'S LAW FROM THE MODERN STANDPOINT.

The motions of the planets nearest the sun do not exactly agree with the motions calculated by the Newtonian theory. Also, there are slight discrepancies between observation and theory in the motion of the moon and that of Encke's comet. All these effects are very small; the most important discrepancy occurs in the motion of the planet Mercury, which is the planet nearest the sun and the one having the most eccentric orbit. The perihelion of the orbit of this planet, that is, the point of the orbit that is nearest the sun, is slowly changing its angular position relative to the sun. This change is in part produced by the attraction of other planets, but after allowing for these influences a change of about 43 seconds of arc per century remains.

It has been suggested that this change may be produced by a

small planet, or a number of very small planets, revolving close to the sun. It has been held, however, that such an assumption can not entirely account for the anomalous motion of Mercury, and that of Venus, which is the next planet. Also, diligent search has been made for such planets, and none has been observed.

We have thus found astronomical evidence of inaccuracy in Newton's law. Evidence of a different character is obtained

| Newtonian relativity. | Michelson-Morley experiment. Velocity of light. | Rayleigh-Brace experiment. Double refraction. |

| Trouton-Rankine experiment. Electrical resistance. | Trouton-Noble experiment. Rotation of condenser. |

| Velocity of light independent of velocity of source. | Independence of velocity. | Velocity of light independent of fields. | Space is Euclidian. |

| Invariance to Lorentz transformation. |

| Relativity of time and space. | Minkowski space analysis. | Impossibility of velocity greater than that of light. |

RELATIVITY.

from the theory of relativity. On account of its bearing upon this question, and because we shall later have occasion to compare the ordinary theory of relativity with a new one of different character, a diagram is presented showing the principles upon which the theory of relativity is based, and some of those which can be deduced from it. This is not by any means intended as a complete account of this theory, but merely as a convenient summary of the more important principles.

THE OLDER THEORY OF RELATIVITY.

The development of the theory of relativity has been the result of the observation of the principle of the independence of velocity, according to which it is impossible by any means to observe or determine an absolute velocity through space; or, all physical phenomena in an isolated system as they appear to an observer within the system are independent of the velocity. There are some other physical principles very much like this; for there are some laws of physics that are applicable at all points in space, the laws that determine the manner in which a system will change with time, which connect its condition at one time, which condition we call the cause, with its condition at a subsequent time, which we call the effect. It is also true that these general laws hold true at all times. Hence we have a principle of independence of time. They are also independent of the orientation of the system in space. Hence we have a principle of independence of orientation. And we have now to consider the principle of independence of velocity. This of course applies only when the velocity is uniform and in a straight line, otherwise there is acceleration. So far as mechanical effects are concerned this principle is not new. It formed part of the mechanics of Newton. It is an every-day observation, for you in this room can not now tell me how rapidly you are moving nor in what direction, in spite of the fact that we have a velocity relative to the sun of about 1100 miles a minute.

In the past it has been held only that mechanics alone gives us no criterion of absolute velocity, but since light was supposed to be propagated by some all-pervading medium, and to travel with a constant velocity relative to this medium, it was thought that experiments with light or other electromagnetic phenomena should enable us to determine our absolute velocity through the ether. For instance, if we are moving in the same direction as a beam of light the apparent velocity of light as observed by us should be the difference between its true velocity and our own velocity, while if we measured the velocity of light moving in the direction at right angles to our motion this should give us more nearly the true velocity, and the comparison of these results should enable us to calculate our own velocity. This is essentially

the famous experiment of Michelson and Morley; but they found that the apparent velocity of light moving in different directions is the same, just as though the earth were stationary in space.

Since this experiment several other attempts have been made to observe the effects of the velocity of the earth. Thus it had been suggested by Fitzgerald and by Lorentz that the Michelson-Morley result would be accounted for if a moving body were always contracted in the direction of motion by a certain amount. The experiments of Rayleigh and Brace were for the purpose of finding whether this contraction causes an isotropic transparent body to become doubly refracting. They found no such result, and this and other experiments lead to the conclusion that although such a contraction may be apparent to a stationary observer, neither the contraction nor any other internal evidence of the velocity is apparent to an observer within the moving system.

There is other evidence supporting the principle of independence of velocity; I have given only some of the most important.

From the principle of independence of velocity we may deduce certain mathematical conditions with which general physical equations must comply. Here again there is an analogy with the more familiar principles of independence of orientation, and of position. Thus the independence of position requires that if in any general equation we make the substitutions:

$$x = x' + a$$
$$y = y' + b$$
$$z = z' + c$$

the new equation is of precisely the same form as the old, having merely x', y', z' where the old had x, y, z. The equation is said to be invariant to the transformation.

The principle of independence of orientation requires that general equations should be invariant to a transformation which represents a change of orientation, thus

$$x = x' \cos \theta - y' \sin \theta$$
$$y = y' \cos \theta + x' \sin \theta$$
$$z = z'$$

represent the case in which the change in orientation is a rotation through the angle θ about the z axis. If we apply this trans-

formation, for example, to the Laplace equation of gravitational potential,

$$\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} + \frac{\partial^2 \phi}{\partial z^2} = 0,$$

we obtain

$$\frac{\partial^2 \phi}{\partial x'^2} + \frac{\partial^2 \phi}{\partial y'^2} + \frac{\partial^2 \phi}{\partial z'^2} = 0,$$

and this equation is invariant to the transformation. Now it can be proved that any differential expression involving x, y, z, and a limited number of dependent variables and their derivatives up to a specified order, if it is invariant to such transformations, is expressible as a function of a certain small number of independent differential forms, of which the Laplacian given above is an example. By the methods of the theory of invariants the number of possible independent forms or differential parameters can be determined and the forms themselves can be found. This is the basis of the ordinary three-dimensional vector analysis.

The principle of independence of velocity leads us to similar results. It requires that all general equations should be invariant to a certain transformation. If the velocity is in the direction of the x axis the transformation is

$$x = \frac{x' - \beta c t'}{\sqrt{1 - \beta^2}}, \quad y = y', \quad z = z', \quad ct = \frac{ct' - \beta x'}{\sqrt{1 - \beta^2}},$$

where c is the velocity of light, and $\beta = \frac{v}{c}$ where v is the velocity of the system. A transformation applying when the velocity is in any direction can of course be written. This transformation was first employed in an imperfect form by Lorentz in the consideration of the electrodynamics of a moving system; it is known as the Lorentz transformation. It was afterward deduced by Einstein upon the basis of certain postulates relative to the velocity of light.

From the principle of the independence of velocity, and the observations which support it, we conclude that to an observer within a system moving with uniform velocity the velocity of light is the same in all directions.

Einstein assumed also that its velocity is independent of the velocity of the source. Of this we have good observational evidence, of which I will mention only that presented by binary stars. Consider for simplicity the case in which a small star is

revolving around a larger one with the earth in the plane of the star's orbit. Suppose we observe the times at which the star reaches the two extremes of its orbit. These times are at equal intervals, but in one case the star is moving toward us while in the other it is moving away, and if the velocity of the star contributed to the velocity of the light the events would not appear to occur at equal intervals and might even be observed in the wrong order.

Einstein made a third assumption relative to the velocity of light, namely that it is independent in free space of the influence of any surrounding objects or of the electric, magnetic or gravitational fields they produce. This agreed with observation so far as observations had been made, but we shall see that the theory of gravitation which Einstein developed later is not in harmony with it.

It should be mentioned here that Einstein assumed that space is Euclidian. This assumption is made in practically all physics and is certainly not far from the truth. I mention it especially here because in some later work he considers that it is not true. The assumption is equivalent to the acceptance of the principle of Euclid that the square of the length of a straight line is equal to the sum of the squares of its projections on rectangular axes:

$$s^2 = x^2 + y^2 + z^2$$

With these conditions the required transformations are merely the relations which must exist between the coördinates employed by a stationary observer and those employed by a moving observer in order that to both of them a light wave from a point source shall appear to form a spherical wave, that is, have the same velocity in all directions.

Just as independence of orientation and position lead to the ordinary three-dimensional vector analysis, the addition of the independence of velocity leads to a set of differential parameters involving the four independent variables x, y, z and t. For the special case in which the system is stationary each of these parameters must reduce to one or more of the three-dimensional forms. For example, the wave equation:

$$\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} + \frac{\partial^2 \phi}{\partial z^2} - \frac{\partial^2 \phi}{\partial (ct)^2} = 0$$

is invariant to the Lorentz transformation if ϕ is a scalar (as

well as to the orientation transformation) and reduces when $\frac{\partial \phi}{\partial(ct)} = 0$ to the equation of Laplace.

The equation of Laplace, which represents Newtonian attraction when ϕ is gravitational potential, is not invariant to the Lorentz transformation, and of course Newton's equation is not invariant either. Thus we have an evidence of the inaccuracy of Newton's law. We have shown in essence that if a system of bodies followed Newton's law as observed by one observer, they would not appear to follow the law as seen by an observer moving relative to the first with a uniform velocity.

Minkowski has shown that the Lorentz transformation is strictly analogous to the orientation transformation in that it represents a rotation or change of orientation in an imaginary space of which the coördinates are x, y, z, and ict, where i is the imaginary quantity $\sqrt{-1}$. As to whether you regard this four-dimensional space as real (in the physical sense, as distinguished from the mathematical) or as merely a chance mathematical analogy, you may take your choice. It will depend upon your criterion of reality, and that is more or less arbitrary. But whatever its philosophical interpretation it is extremely useful. Just as the ordinary vector analysis enables us to express general physical equations much more simply than without its use, so the four-dimensional analysis produces a further condensation, and it is not a mere abbreviation but a real simplification by the elimination of unessential framework.

It is noteworthy that the Lorentz transformation expresses the time of one observer in terms of the time and position of the other, and *vice versa*. Thus time and space are relative. From the Minkowski point of view, there is no particular direction in the four-dimensional space which must be taken as the time direction. A moving point in ordinary space corresponds to a stationary line in Minkowski space, while a stationary point corresponds to a straight line having the direction of the time axis; but the direction of the time axis appears different to observers on systems on different lines.

It may be noted that this argument does not prove that there are no independent space and time and no absolute velocity, but only that it is impossible to determine them by observation. The distinction is perhaps immaterial, but there is no objection to

anyone's continuing to imagine space and time as distinct and velocity as absolute if only he realizes that no observation can give evidence of them. However, aside from the persistence of old ways of thinking there is no more reason for this than for imagining absolute position, absolute time or absolute orientation.

The theory of relativity has taken a little more away from the already diminished prestige of the theory of an ether. I am not aware that its existence can be actually disproved by the relativity theory, although it can not be the kind of an ether it was once imagined to be.

RELATIVITY AND EVIDENCE AGAINST NEWTON'S LAW.

The theory of relativity presents evidence against the possibility of gravitational force or anything else having a velocity greater than that of light.

In a system considered as stationary suppose that some impulse or signal is sent from the point x_0 to the point x, with uniform velocity u. The time that elapses will be

$$\Delta t = t_1 - t_0 = \frac{x_1 - x_2}{u}.$$

Now consider another system moving relative to the first in the same direction with velocity v.

To an observer in the second system the interval of time would appear different. Its apparent value can be calculated by applying the Lorentz transformation for the time. The result is

$$\Delta t' = t_1' - t_0' = \frac{t_1 - \frac{v}{c^2}x_1}{\sqrt{1 - \frac{v^2}{c^2}}} - \frac{t_0 - \frac{v}{c^2}x_0}{\sqrt{1 - \frac{v^2}{c^2}}}.$$

From this equation we can eliminate x_0, x_1, t_0, and t_1, by means of the previous equations; the result is

$$\Delta t' = \frac{1 - \frac{uv}{c^2}}{\sqrt{1 - \frac{v^2}{c^2}}}\Delta t$$

It will be noticed that if $\frac{uv}{c^2} > 1$ the two intervals of time will have opposite signs. Now v can have any value up to the velocity of

light c. For instance, electrons have been driven with velocities approaching that of light, although to do this it is necessary to impart a large amount of energy to them. Hence if $u>c$, v can be made so large that $\frac{uv}{c^2} >1$. In this case an observer on the moving system would see the impulse reach x_1 before it left x_0. The order of cause and effect would be reversed and by the principle of the independence of velocity the observer in the moving system has as much right to consider his observations real and his own system stationary as an observer in the system we designated arbitrarily as stationary. The invariability of the sequence of cause and effect forms a principle antecedent to all other laws of physical change. The process here presented should not be confused with certain common observations which present an apparent resemblance to a reversal of cause and effect. For instance, if a high-velocity projectile is fired above the head of an observer he may hear the sound of the projectile and later hear the report of the gun. But if he calculates the times of occurrence with consideration of the velocity of sound, he finds cause and effect occurred in the proper order. But in the process described before, the times presented as those of the moving observer are those he would calculate after allowing for the velocity of light.

This conclusion is inconsistent with Newton's form of the law of gravitation, which states that the force is inversely proportional to the square of the distance without regard to the velocities of the masses and therefore requires an infinite velocity of transmission.

There appears to be an impression among physicists that there is something about astronomical observations that requires that the velocity should be infinite, or at least much greater than that of light. This impression has had its origin in some early work by Laplace and some work by Lehmann-Filhés and by Hepperger. These investigators endeavored to calculate what velocity gravitational transmission would need to have to account for the variation from Newton's law exhibited by the motion of the planet Mercury. They concluded that the velocity would need to be exceedingly high. But in order to make their calculations it was necessary to make some assumption as to the manner of action of gravitation. Since Newton's law was not to be used, a new law must be assumed, and although they thought there

was logical basis for the laws they assumed, there is really enormous latitude of choice in this matter. It is quite as difficult to generalize from Newton's law, assumed to be applicable for a stationary system, to a general law applicable when velocities are involved, as though one familiar with Coulomb's law of the force between electric charges at rest should attempt to extend it to charges in motion, without a knowledge of the magnetic field.

All three of these investigators assumed that the force on the attracted body is not in the actual momentary direction of the attracting body, as required by Newton's law, but in the direction of the position the attracting body occupied when the gravitational wave left it. Laplace assumed that the magnitude of the force is the same as that indicated by Newton's law, the distance being taken as the actual momentary distance; while the other two employed the distance to the old position of the attracting body.

Laplace estimated that the velocity would need to be 100,000,000 times that of light to produce no more anomalous motion in Mercury than that observed. A velocity equal to that of light would have led to very great disturbances in the solar system, by his theory.

Hepperger, with the other theory of the manner of action, concluded that the velocity must be about 500 times as great as that of light.

On the other hand, in 1898 Gerber proposed still another theory of the manner of action, and from it calculated the necessary velocity to account for Mercury's perturbation, and found that it agreed well with the velocity of light.

We have now considered the evidence against Newton's theory, which may be summarized as follows:

1. It does not entirely account for the motion of Mercury and the motions of some other heavenly bodies.

2. The equation is not invariant to the Lorentz transformation.

3. It represents an infinite velocity of transmission, while the theory of relativity indicates that no velocity can be greater than that of light.

The last two of these are dependent upon the older theory of relativity, which depends in part upon postulates which Einstein has rejected in his recent theory of gravitation. This more recent theory is also inconsistent with Newton's theory, except under

certain conditions. We may now consider in what respects the law is supported by modern observations.

MASS FORCE AND ENERGY.

What has been presented so far is sufficient to show the importance of distinguishing between observations and theories that are valid only for velocities that are small relative to that of light, and those that are valid strictly for all velocities. The number of physical experiments that have given information valid for velocities approaching that of light is extremely small, and they have almost all been carried out in recent years. We must therefore be prepared, with open mind, to change if necessary some of our views relative to familiar principles when we attempt to apply them in so precise and rigorous a manner that these velocity effects must be taken into account. We must consider even the definitions of the most familiar physical quantities. The principles of Newton are valid for velocities that are negligibly small; as to their validity for velocities near that of light Newton had no evidence. He, of course, had no reason to suppose that the velocity of light has anything to do with them.
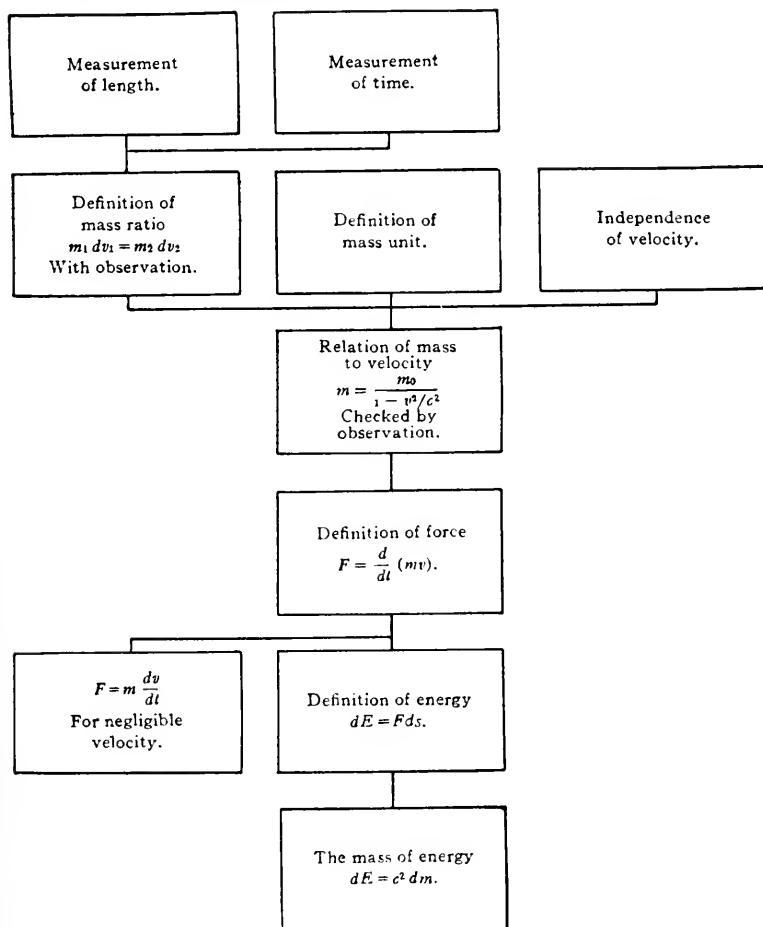
It appears therefore well worth while to consider our definitions of mass and force, for in spite of the fact that almost every high school student in physics is asked to define these quantities it is not easy to define them, even in terms of ordinary Newtonian mechanics. The definitions are to a certain extent arbitrary; one may define force in terms of mass or mass in terms of force, but one or the other must of course be defined independently. It is usual even among scientific writers to say, " We will accept the customary conception of mass and define force in terms of it," or, " We will employ the term ' force ' with its usual meaning and define mass by the relation, force equals mass times acceleration."

I will not attempt an exhaustive treatment of these basic principles, but for the present purposes some statement of the meaning of the words we employ seems quite important, and I will again employ a diagram to present without too much detail a summarized statement of a single one of the possible sets of definitions and of certain important principles.

A definition of mass will first be given. If dv_1 and dv_2 represent the changes of velocity that two bodies undergo, each

as the result of the presence of the other body, the ratio of their masses m_1 and m_2 is defined by the equation $m_1 dv_1 = m_2 dv_2$. For completeness a unit of mass must be defined. This unit is familiar. It is found by observation that the mass ratio so defined is

Measurement of length.	Measurement of time.

Definition of mass ratio $m_1 dv_1 = m_2 dv_2$ With observation.	Definition of mass unit.	Independence of velocity.

Relation of mass to velocity
$$m = \frac{m_0}{1 - v^2/c^2}$$
Checked by observation.

Definition of force
$$F = \frac{d}{dt}(mv).$$

$F = m\dfrac{dv}{dt}$ For negligible velocity.	Definition of energy $dE = Fds.$

The mass of energy
$$dE = c^2 dm.$$

MASS FORCE AND ENERGY.

independent of the nature of the interaction between the two bodies, of the presence of neighboring bodies, and of the order in which the masses of the bodies are compared. I will not attempt to analyze these observations in detail. They form a part of the evidence of the conservation of mass.

It was formerly supposed that the mass ratio is also independent of the velocities of the bodies, as it is for small velocities, within the limits of observation. This is not true for large velocities, however. By means of the principle of independence of velocity we can determine the relation of the mass of an object to its velocity.

Consider two observers, one in a system considered stationary, the other in a system moving relative to the first with a uniform velocity v. Suppose that in each system there is a body and that the two bodies are exactly alike if each is examined by an observer moving with the body. Suppose that as the body in the moving system comes opposite to that in the stationary system the two are caused to act upon each other, by impact or otherwise, producing a change in velocity in each.

A's object appears to him to undergo a certain change of velocity du. By the principle of independence of velocity, since the bodies are the same, B's object appears to B to undergo the same velocity change in the opposite direction. By the Lorentz transformation we can find what this velocity in B's coördinates will be when expressed in A's coördinates. For illustration we will here assume that the change of velocity is at right angles to the direction of motion; a rigorous treatment of the general case gives the same result. In this case the measure of length in the direction of motion of the objects is the same in the two systems, but the units of time are in the ratio of $1 : \sqrt{1 - \frac{v^2}{c^2}}$. Hence the change of velocity of the object in the moving system in the units of the stationary observer is $\sqrt{1 - \frac{v^2}{c^2}}\, du$, and our definitive equation of mass gives $m_0 du = m \sqrt{1 - \frac{v^2}{c^2}}\, du$, where

m_0 = mass in stationary system
m = mass in moving system.

Hence

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

With the definition of mass that has been employed we find that the mass of a moving object, while dependent upon velocity, is independent of the relation of the direction of the velocity

to the direction of the change in velocity, as is shown if in our imaginary systems we consider the bodies moving in other directions than that we have chosen for simplicity. With another definition of mass, this is not the case, and we are forced to speak of transverse mass and longitudinal mass. Thus it appears that definitions have some importance.

This equation agrees very well with the actual observations of Bucherer and Hupka on the relation between the mass of an electron and its velocity. It agrees approximately with the earlier observations of Kaufmann, but it is now admitted that these observations must have been slightly in error. We have thus a striking agreement between observation and an entirely independent theoretical conclusion from the principle of independence of velocity.

We will now define the force exerted on a body A by a body B as $F = \frac{d}{dt}(mv)$, where $\frac{d}{dt}(mv)$ is the difference between the time rate of change of momentum of A in the presence of B and that in the absence of B. This is equivalent to $F = m\frac{dv}{dt} + v\frac{dm}{dt}$, and in the special case in which v is negligibly small it becomes $F = m\frac{dv}{dt}$. This equation is itself sometimes used as the general definition of force; but by the present definitions it is true only when velocities are negligibly relative to that of light, as in ordinary mechanics.

An element of kinetic energy may now be defined as the product of the total force exerted on a body and the element of distance through which the body moves in the direction of the force: $dE = Fds$. Since both the force and the motion pertain to a particular body, the kinetic energy does also.

The equations presented lead to the striking result of the proportionality of changes in kinetic energy and the accompanying changes in mass. This is obtained by elimination, as follows:

From the definition of energy,

$$dE = Fds.$$

From the definition of force,

$$dE = \frac{d}{dt}(mv)\,ds = \left[\frac{ds}{dt}\frac{d}{ds}(mv)\right]ds$$
$$= vd(mv)$$

From the equation,

$$m = \frac{m_o}{\sqrt{1 - \dfrac{v^2}{c^2}}}, \qquad v = c\sqrt{1 - \frac{m_o^2}{m^2}} ;$$

$$dE = c\sqrt{1 - \frac{m_o^2}{m^2}} \, d\left[c\sqrt{m^2 - m_o^2} \right]$$

$$= c^2 \, dm$$

This idea is not entirely new, for Maxwell's electromagnetic theory led him to the conclusion that light exerts an impulse upon a surface upon which it falls, and this was later confirmed by observation. An application of the principle of conservation of momentum led to the conclusion that light carries with it a moving mass; and the relation of this mass to the energy of the light is like that stated above.

From this point of view any change in the kinetic energy of a body, which includes the individual kinetic energies of its atoms and molecules, results in a change in its mass. An increase of one gram requires an energy increase of 9×10^{20} ergs.

This factor is so large that the amount of energy that can be added to a body by heating it, for example, would not produce a change of mass that could be detected. This energy of 9×10^{20} ergs equivalent to one gram, is equal to the heat of combustion of about 1600 tons of gasoline.

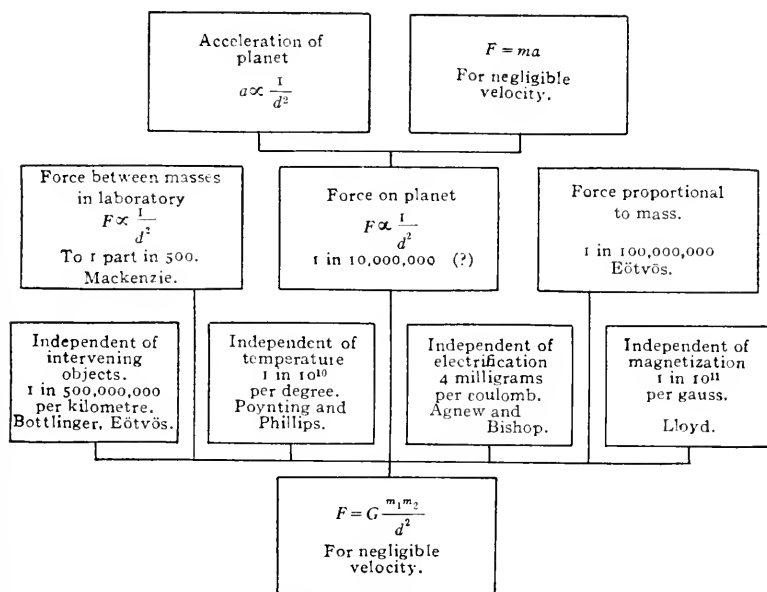### GRAVITATION WHEN VELOCITIES ARE NEGLIGIBLE.

We will now return to the subject of gravitation. We have found that the three pieces of evidence against Newton's law are all associated with the velocities of the bodies. We have no evidence against the law as applied to stationary bodies, and on the other hand much evidence collected since Newton's time has strengthened its position in this respect. A diagram of the evidence supporting the law as applied only to bodies with velocities small relative to that of light is therefore presented. Indications are given of the degree of accuracy with which it has been checked.

The astronomical evidence has already been presented briefly. It indicates, I believe, that the force is inversely proportional to the square of the distance within about one part in 10,000,000, although I am a little in doubt relative to this datum. Experi-

ments on masses in the laboratory by the torsion balance method show that the law is followed within one part in 500.

Eötvös has used some exceedingly sensitive torsion balances for the study of problems connected with gravitation. For the study of the relation of gravitative force to mass he used a balance consisting of a horizontal rod having at its ends two equal masses of different materials, and supported in the middle by a silica fibre. The two masses, like all masses on the earth, are acted upon by the force of gravity and also by the centrifugal

Acceleration of planet $a \propto \dfrac{1}{d^2}$		$F = ma$ For negligible velocity.

Force between masses in laboratory $F \propto \dfrac{1}{d^2}$ To 1 part in 500. Mackenzie.	Force on planet $F \propto \dfrac{1}{d^2}$ 1 in 10,000,000 (?)	Force proportional to mass. 1 in 100,000,000 Eötvös.

Independent of intervening objects. 1 in 500,000,000 per kilometre. Bottlinger, Eötvös.	Independent of temperature 1 in 10^{10} per degree. Poynting and Phillips.	Independent of electrification 4 milligrams per coulomb. Agnew and Bishop.	Independent of magnetization 1 in 10^{11} per gauss. Lloyd.

$$F = G \frac{m_1 m_2}{d^2}$$

For negligible velocity.

GRAVITATION WHEN VELOCITIES ARE NEGLIGIBLE.

force resulting from the earth's rotation. If the balance is set so that one mass is nearer the earth's equator than the other, a greater portion of the force on this mass will be centrifugal force than that on the other mass, which is nearer the earth's axis of rotation. If the ratio of gravitational force to mass is not the same for the two materials, the balance will have a tendency to turn, if set at a suitable angle. Whether a turning couple exists can be determined by rotating the top of the fibre through 180° and observing whether the suspension turns through exactly the same angle. The method is surprisingly sensitive, and he

showed that the attracting force is proportional to mass with an accuracy of one part in 20,000,000 and in some experiments of one part in 100,000,000.

In order to investigate the influence of intervening masses Eötvös employed a balance of the form shown in Fig. 1. The masses on this balance are attracted not only by the earth, but also by the sun. Suppose this apparatus is observed at sunset. All objects near the suspension being stationary, the only changes in

Fig. 1.
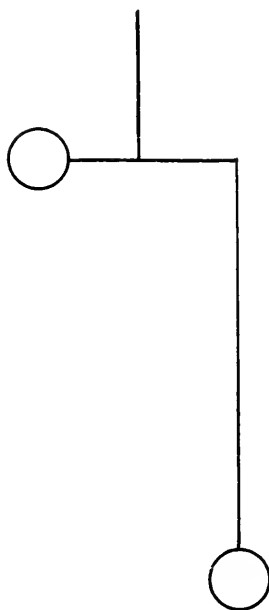
force to be considered are those resulting from changes in the relative position of the sun. Suppose the suspension placed with the arm perpendicular to the direction of the sun. In the following diagram the arm is seen endwise.

Before the sun begins to set there will be no obstruction between the masses and the sun, and the forces on them will be the same, and there will be no torque. But when the sun has set, a considerable thickness of the earth's crust will come between the balance and the sun, and just as the sun sets this will be considerably greater (by several kilometres) for the lower

mass than for the upper, and if the earth exerts any shielding action the lower mass will be attracted less strongly and the suspension will turn. No effect was observed, although a change of one part in 100,000,000 per kilometre of the earth intervening could have been detected.

Another test is afforded at the time of an eclipse of the moon, for at that time the earth is directly between the sun and the moon, and if there were any shielding action the motion of the moon would be disturbed. Bottlinger has ascribed some very small observed perturbations to this cause, but they correspond to a shielding action of only one part in 1,000,000,000 per kilometre of the earth; and it is likely that the observed effects were observational errors or caused by something else. At least we can

FIG. 2.

TO THE SUN

THE EARTH
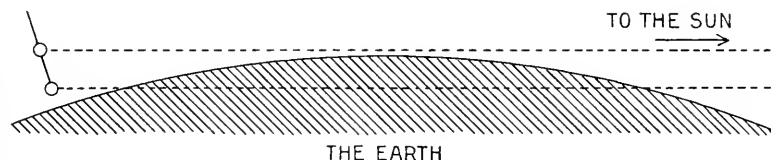
conclude that the shielding is not more than one part in 500,000,-000 per kilometre.

Some observations on the effect of temperature, those of Shaw, are not in accord with the datum I have given in the chart but indicate a very large effect of temperature, when both of the attracting masses are objects in the laboratory, and the larger of the two is heated. However, they were obtained by a method having possible sources of error, and I do not think they should be considered conclusive.

The theory of relativity leads to the conclusion that increasing the kinetic energy of a body increases its mass according to the equation $dE=c^2dm$, and therefore that increasing the temperature of a body would increase its mass, but the effect would be too small to be observed. It would of course not be contrary to the stated law of gravitation, but would represent merely the transfer of a very small mass from one thing to another.

The experiments on the effect of electrification were made by weighing a condenser, charged and uncharged. Charging the condenser of course merely represented a transfer of electrons

from one side of the condenser to the other; so that the experiment merely indicates that this change produces no change in weight, not that an electron has no weight.

EINSTEIN'S THEORY OF GRAVITATION.

Einstein's theory of gravitation is based upon his equivalence hypothesis, according to which a uniform gravitational field of force is exactly equivalent to the effects of an acceleration of the system considered, when there is no gravitational field; so that no possible experiment can distinguish between them.

There are some common observations that illustrate this hypothesis and support it as far as they go. For instance, if we are riding in an elevator, as long as it is moving up or down with a uniform velocity we feel the familiar effects of gravitation and our feet press upon the floor with the same force. If the elevator is accelerated upward we seem to weigh more, the force between the floor and our feet is greater, and as far as we can observe, the effect is the same as though the force of gravity were greater; and the ordinary effects of gravity are the same, as far as we can observe, as those that might be produced by an acceleration. Einstein assumes that this relation, which we observe is at least approximately true, is strictly true no matter whether we observe ordinary mechanical effects or any phenomena whatever.

In order that it may be strictly true, it is necessary that the acceleration produced upon freely moving bodies by a gravitational field should be the same for all bodies; in other words, that weight should be proportional to mass. That this is true within very narrow limits has been shown by the work of Eötvös, already described. The equivalence hypothesis is thus dependent upon this observational principle.

This hypothesis is analogous to some principles we have already considered, such as the principle of independence of velocity. That deals with uniform velocity; the new hypothesis deals with uniform acceleration. However, there are differences which should be considered. The principle of independence of velocity states that an absolute velocity cannot be detected by any means. The equivalence hypothesis does not state that effects of uniform acceleration in the absence of gravity cannot be detected,

but only that the effects are not distinguishable from those
of a uniform gravitational field. Further, the principle of inde-
pendence of velocity is based upon observations involving not
only mechanical effects, but also electrical and optical effects;
and sufficiently accurate observations have been made to find
the effects predicted from the old theory of a stationary ether
if they existed; while Einstein's equivalence hypothesis had for
its support only mechanical observations, for optical or electri-
cal experiments of the necessary refinement had not at the time
been made.

The applicability of the equivalence hypothesis is limited to
uniform gravitational fields, and consequently to uniform accele-
ration. We cannot imagine the complicated accelerations, exist-
ing, for instance, throughout the cars of a moving train, as being
equivalent to any changing gravitational field. Such a motion
involves not only acceleration, that is, the second derivatives of
position relative to time, but also the higher derivatives of posi-
tion relative to time. Similarly the principle of independence
of velocity applies only to uniform velocity, involving only the
first derivative of position relative to time, not to acceler-
ated velocity.

Making use of the equivalence hypothesis, Einstein em-
ployed it for a determination of the necessary form of the gravi-
tation laws, by employing transformations of coördinates such as
would correspond to the assumed equivalence of the two kinds
of fields. His first step was to consider a transformation applied
to the coördinates of the accelerated system such that referred
to the new coördinates it would be a system at rest. In so doing
he considered first that the space might or might not be Euclidian,
and he also introduced the idea of a generalized theory of rela-
tivity. Before attempting to make clear his application of
the equivalence hypothesis it is therefore desirable to give a
little consideration to the principles of the transformation
of coördinates.

CO-ORDINATE TRANSFORMATIONS AND GENERALIZED RELATIVITY.

We shall have occasion to consider changes not only of the
coördinates of ordinary space but of a space that does not follow
the geometry of Euclid, of a curved space, for Einstein has con-
sidered it necessary to introduce such a conception into his theory.

In so doing I do not wish to alarm you unduly as to the danger that space is really curved. The evidence does not yet force us to this conclusion, but if it is curved this is not so fantastic an idea as might at first appear. The idea has played a very important part in Einstein's theory and it is quite proper and indeed necessary that physicists should consider this possibility.

It is much easier to visualize the problem if we consider not a four-dimensional nor even a three-dimensional, but a two-dimensional curved space. Suppose that we have here a curved surface and imagine that some kind of beings inhabit this two-dimensional space, and that all the phenomena that they can observe are within that space, so that to them a three-dimensional space is a fantastic dream.

They can measure their space and calculate the curvature, in some cases at least, provided it is not too slight. Now how do they measure it? How do we measure our space? We take a metre stick and we observe that so far as we can see this stick has the same length no matter which way we turn it nor where we place it. Yet we really do not know that its length does not change; we know only that every measuring device and every object we can examine when their orientation and position are changed, change their lengths in the *same ratio*, so that two metre sticks that coincide when placed together in one position coincide when placed together in any other. This principle, which is an exemplification of the principles of independence of position and independence of orientation, is one of the most fundamental principles of physics, being antecedent to our conception of the measurement of length. We realize that our metre stick may not have the same length in all positions, but since we can not determine the change, we adopt the *convention* that it shall be considered constant.

That this convention, though a wise one, is not a necessary one I can illustrate by exhibiting a universe in which the situation is otherwise. Such a universe may be seen in a concave mirror. I have here a sheet of rectangular coördinate paper, and the lines appear to me equally spaced, and mutually parallel or at right angles. But here is a man in the mirror who has a sheet of paper on which the lines are curved, and they are not at right angles. Yet if he, like myself, takes a unit length and moves it along one of the lines he finds its length always corre-

sponds to the space between two divisions, because the unit changes as he moves it. And if I check the perpendicularity of these lines by holding a triangle first in one angle and then in its supplementary angle, he does the same. but his triangle changes when he turns it around, and he thinks his angles are right angles. But when he looks out of the mirror at us our space appears distorted, and he says, " That fellow out there is crooked and drunk, but my space is uniform and straight, and I use Euclid's geometry." In this point of view he is as justified as we are, and he exemplifies the wisdom of our convention that the length of our metre stick shall be considered as a constant.

With this convention the inhabitants of the two-dimensional space can make measurements in it and observe its curvature, just as surveys of the earth's surface can give evidence that the surface is approximately spherical, without the need of observing the celestial bodies, which are outside the surface. They will find it useful to employ a set of coördinates. If they think their surface is plane they will perhaps endeavor to employ Cartesian rectangular coördinates, but they may find that the lines in this system which in one region appear parallel will, if sufficiently extended, eventually meet, contrary to the axiom of Euclid. An axiom may be defined as an observation that has been so universally impressed upon us that we cannot imagine the possibility of the situation being otherwise. Euclid could not imagine that parallel lines in three-dimensional space should ever meet. Our imaginations have been further developed.

After setting up their coördinate or parametric lines, which may be arbitrarily any two infinite sets of lines such that one line of each set passes through each point of the surface, they will need to be able to estimate the length of a line in any arbitrary direction. If ds is the length of an element of such a line and du and dv are elements of lengths of the parametric lines, it can be shown by an elementary calculation that ds is given by an equation of the form

$$ds^2 = E\,du^2 + 2F\,du\,dv + G\,dv^2$$

in which the quantities E, F and G are in general different in different parts of the surface. From this they can determine something about the curvature of the surface. A surface has two principal radii of curvature ρ_1, ρ_2 in different directions.

From the above quantities they can determine what is called the Gaussian curvature, which is

$$\frac{1}{\rho_1\rho_2} = \frac{1}{2H}\left\{\frac{\partial}{\partial u}\left[\frac{F}{EH}\frac{\partial E}{\partial v} - \frac{1}{H}\frac{\partial G}{\partial u}\right] + \frac{\partial}{\partial v}\left[\frac{2}{H}\frac{\partial F}{\partial u} - \frac{1}{H}\frac{\partial E}{\partial v} - \frac{F}{EH}\frac{\partial E}{\partial u}\right]\right\},$$

in which

$$H = \sqrt{EG - F^2}.$$

For example, if we substitute $E = G = 1$, $F = O$, we find that the curvature is zero and the element of length is given by

$$ds^2 = du^2 + dv^2$$

which is the geometry of a plane with rectangular coördinates. The observers in the surface cannot determine ρ_1 and ρ_2 separately. If the Gaussian curvature is everywhere zero, the surface will appear to them to have all the properties of a plane, yet it may be what is known as a " developable surface," a surface which can be produced by bending a plane without stretching.

Now suppose that the inhabitants of the surface desire to use a different set of coördinates connected with the old ones by some relations :

$$u_1 = f_1 (u, v)$$
$$v_1 = f_2 (u, v)$$

If we apply this transformation to the ds^2 we obtain an expression of the same form, namely,

$$ds^2 = E_1 du_1^2 + 2F_1 du_1 dv_1 + G_1 dv_1^2,$$

where E_1, F_1 and G_1 are new quantities. The Gaussian curvature may now be obtained by the same equation as before, using E_1, F_1 and G_1 in place of E, F, G. Thus the curvature is invariant to any transformation of the coördinates, it is an intrinsic property of the surface, independent of the coördinates we use to express it.

In Einstein's problem we have to consider transformations involving not only position and time but also forces, and this seems to complicate the matter. Yet we measure forces only by the changes of position they produce. In fact, all *exact* observations of any kind are observations of the simultaneous coincidences of things in space. When we measure a mass, we do not put the mass in the same space as a standard mass and see whether they are alike, but observe under what conditions the pointer of a

balance coincides with the zero point on the scale. In electrical measurements we note the coincidence of the pointer of a galvanometer with a point on a scale or a spot of light from a galvanometer mirror with a scale.

It is true that we have physiological sensations of magnitude that are not obviously of this character. We gain some idea of the weight of a body by holding it in the hand, and we have sensations of temperature, color, etc. The visual estimation of length is associated with the coincidence of the image on the retina with particular points of the retina. We cannot analyze all these physiological processes, because we do not understand brain mechanism. Perhaps we may think of the coincidence of the excitation conveyed by a nerve, with a particular memory cell of the brain; but we need not worry about this, for physiological estimates are only qualitative, and physical measurements are never based upon them directly.

When a body moves in a straight line with uniform velocity we consider that there is no force acting upon it; this accords with our definition of force in terms of change of motion.

Einstein has proposed a new generalized principle of relativity. According to this principle all general physical laws must be expressible in such a form that they are invariant to any transformation of coördinates. It has been pointed out that the only things we ever really observe are coincidences, and coincidences do not depend upon coördinates.

If we confine our attention first to ordinary space, without regard to time, we can readily admit that this must be true; and we are accustomed to using at will rectangular, spherical, cylindrical, ellipsoidal or other coördinate systems, as convenient. It is essential, however, that we should have to start with a principle which harmonizes with the true nature of our space, Euclidian or curved. Our expression for the length of an element of a straight line includes the specifications of the curvature, if it exists, and any transformations whatever of the coördinates of the space itself leave these specifications unchanged.

Minkowski showed on the basis of the Lorentz transformation the advantage of considering a four-dimensional space with coördinates x, y, z and ict. Minkowski's space is Euclidian; its curvature is zero. Einstein has also treated time as a fourth space coördinate, but he has discarded the older theory of rela-

tivity, because it was based upon the postulate of the constancy of the velocity of light, and his four-dimensional space is therefore not necessarily Euclidian, and leaves the curvature to be determined by the requirements of his equivalence hypothesis.

EINSTEIN'S THEORY OF GRAVITATION, continued.

We may now return to the problem of gravitation, and to keep our ideas clear I will repeat our problem. Our premise is that two systems, one accelerated and one having a uniform gravita-

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                    ┌─────────────────────┐
                    │ Weight proportional │
                    │      to mass.       │
                    └─────────────────────┘

┌──────────────┐    ┌─────────────────────┐    ┌──────────────┐
│ Generalized  │    │    Equivalence      │    │ Non-Euclidian│
│ relativity   │    │    hypothesis.      │    │    space.    │
└──────────────┘    └─────────────────────┘    └──────────────┘

                    ┌─────────────────────┐
                    │    Einstein's ten   │
                    │    equations of     │
                    │     gravitation.    │
                    └─────────────────────┘

┌──────────────┐    ┌─────────────────────┐    ┌──────────────┐
│ Deflection of│    │ Shift of wave length│    │Perihelial motion│
│ light by sun.│    │    in sunlight.     │    │ of Mercury.  │
└──────────────┘    └─────────────────────┘    └──────────────┘
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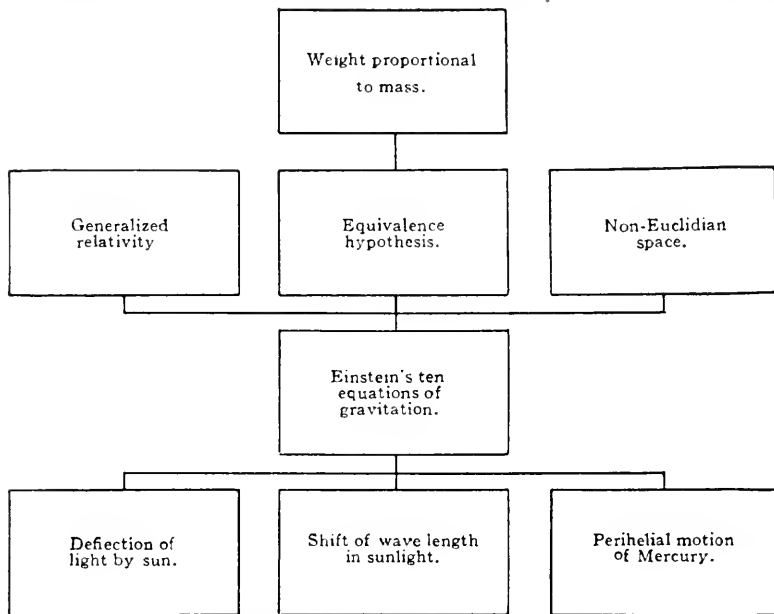
EINSTEIN'S THEORY OF GRAVITATION.

tional field of suitable intensity, appear the same to observers in them. We wish to find the relations that must exist between the space-time coördinates of the two observers in order that this may be true.

Consider the accelerated system, which has no gravitational field. The acceleration must of course be produced by a force, and the force must be applied to the part of the system that forms the support, the part upon which it rests when subjected to a gravitational field without acceleration. It has been specified that the acceleration is uniform; there are no relative accelerations within the system. It is proposed now to apply a transformation

of coördinates so that relative to the new coördinates the system is at rest.

The transformed element of length is of the form :

$$ds^2 = g_{11} dx_1{}^2 + g_{22}{}^2 dx_2{}^2 + g_{33} dx_3{}^2 + g_{44} dx_4{}^2$$
$$+ 2g_{12} dx_1 dx_2 + 2g_{13} dx_1 dx_3 + 2g_{14} dx_1 dx_4$$
$$+ 2g_{23} dx_2 dx_3 + 2g_{24} dx_2 dx_4 + 2g_{34} dx_3 dx_4.$$

The ten coefficients, the g's, are the only necessary characteristics of the transformation. By hypothesis the accelerated system was equivalent to a system with a uniform gravitational field. The g's therefore represent a transformation from a gravitational field to the absence of one ; they represent all the difference between such a field and the absence of one ; they define the gravitational field. In the ordinary Newtonian theory the state of a gravitational field is determined by a single quantity, the potential ; here we have ten quantities. The possible complexity of the theory is thus indicated.

We have now the problem of determining what the g's represent and what are the relations among them ; these relations must consist of or include the equations of gravitation. In this we are aided by the general principle of relativity, from which it follows that the relations must be invariant to all coördinate transformations ; also by the fact that the equations must approach the old law of gravitation when the velocity approaches zero.

Just as the principle of independence of orientation leads to ordinary vector analysis, and that of invariance to the Lorentz transformation leads to a four-dimensional vector analysis, so the general theory of relativity requires invariance to a general transformation and requires the use of a general invariant theory, which has been employed in the form of the tensor analysis or absolute differential calculus of Ricci and Levi-Civita. Any adequate treatment of this in a short time is impossible.

The requirements of invariance to a general transformation, together with the requirement of giving the known equation for zero velocity, greatly limit the possible forms of the gravitation equations. Einstein has been led in this way to the selection of certain equations which appear necessarily true if the truth of the equivalence hypothesis is accepted.

Having found the g's, we can calculate the curvature of the four-dimensional space, by the application of a formula analogous

to that presented for two dimensions, and it is found that there is a curvature, which is zero in a uniform gravitational field, but is positive in space occupied by matter. What is meant by a positive curvature is illustrated in the case of two dimensions by the observation that when the curvature is positive the two principal radii of curvature have the same sign, that is, are on the same side of the surface, as in the case of a sphere. This has led Einstein to the idea that since the curvature of space is always in the same direction, the space may be analogous to a closed surface, such as a sphere; not a true sphere, since the curvature is not constant, but something like a wrinkled sphere. Of course a sphere is only a two-dimensional space existing in three dimensional or higher space. The space we are considering is the four-dimensional space, including time as one coördinate; and if we consider it curved we may imagine it existing in a space of higher dimensions. Our ordinary three-dimensional space would form a part of the four-dimensional space and would share the curvature.

The idea of the space being closed is merely one suggestion; it is not an essential part of the theory. It of course implies that space is finite and contains a finite amount of matter. Also, it leads to many bizarre conclusions. For instance, light radiating from a star in this space would pass completely around the space, if not stopped by intervening matter, and would then come together near its original position forming something approaching an image; but as millions of years would be required for the light to travel around, the original source of the light would usually have moved to a distant point.

It does not seem to me that proof that Einstein's equations are strictly correct would necessarily show that space is curved, for it may be that under certain conditions all our measuring devices in a particular region of space change their length in the same ratio, so that the change is not directly apparent to us, but may lead us to erroneous conclusions relative to the metrical properties of space.

Einstein's theory of gravitation is contrary to his older theory of relativity; not to the principle of independence of velocity, but to some of the conclusions which were drawn from this principle, for in deducing the Lorentz transformation he had assumed that the velocity of light is constant under all conditions, and that space is Euclidian.

The theory has led to three conclusions capable of comparison with observation.

It has accounted satisfactorily for the perihelial motion of Mercury. This has been considered a great triumph of the theory, yet it must be remembered that in 1898, before Einstein's first theory of relativity had been presented, Gerber proposed a comparatively simple law of gravitation which also accounted very well for the motion of Mercury; and it has since been shown that Gerber's theory, unlike Einstein's, accords with the older theory of relativity.

Einstein's theory has led to the conclusion that the velocity of light is variable, depending upon the gravitational potential, and that in consequence, light passing through a variable gravitational field would be deflected. He showed that the light of a star passing close to the sun would be deflected 1.74 seconds of arc. A deflection might be expected for other reasons than those of Einstein. The classical electromagnetic theory, as well as relativity, assign a certain mass to the energy of a ray of light. If this moving mass is subject to gravitation it is to be expected that it will be deflected by a gravitational field. We cannot calculate how much without a law of gravitation applicable to moving bodies. If merely as an example we apply Newton's law, although we believe it is not always applicable to moving bodies, we find the deflection would be just half that predicted by Einstein.

Einstein's theory has also led to the conclusion that an atom in a gravitational field of high potential would vibrate at a slower rate than one in a low potential; and therefore the spectral lines in light from the sun would be shifted a little toward the red, as compared with light produced in the laboratory.

The deflection of the light of a star by the sun can be observed by ordinary methods only during a solar eclipse. Observations were made of the eclipses of 1918 and 1919. Full scientific reports of any of these observations have not been published so far as I know, but some information about them has come from various sources. It was reported that no Einstein effect was observed in the eclipse of 1918. English astronomers appear to have found the effect in the observations of 1919 under more satisfactory conditions for observation, and the amount of deflection agreed with Einstein's prediction. The results of not all of the 1919 observations have been made public. If an effect is observed we have

also to consider the possibility of its being produced by a refraction by the sun's atmosphere.

The predicted displacement of lines in the sun's spectrum is about .008 Angstrom units, which is very small. In searching for this effect it is necessary to avoid confusion with pressure effects, and with the Doppler effect produced by the velocity of the luminous gases. A careful investigation has been made by St. John at the Mount Wilson observatory. To avoid the effects of pressure he has studied some cyanogen lines which are not affected by pressure. He avoided the Doppler effect produced by the rotation of the sun by comparing observations at different parts of the sun's disk. He found no displacement greater than .002 A.

His observations have been confirmed by Evershed at the Kodaikanal Observatory in India. Evershed found in some cases displacements of about the predicted amount near the limb of the sun, but these were variable and appeared to be produced by motion of the luminous gas. This he confirmed very nicely by observing the spectrum of sunlight reflected by Venus from the farther side of the sun. He found there a shift in the opposite direction, indicating that at the time of his observations the gases were moving from the face of the sun around to the opposite side. The Einstein effect would always have the same sign.

The evidence seems at present rather favorable to Einstein's theory, though with this contradictory evidence we cannot yet consider the matter settled.*

If a real deflection of light has been observed it will be necessary to abandon some of the conclusions of the older relativity theory which were deduced from the assumption that the velocity of light is constant. If the deflection has been observed this alone hardly proves the correctness of Einstein's theory of gravitation, although it is strong evidence in its favor; as I have pointed out, a deflection might be expected upon other theories.

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* Since the above was prepared for publication, it has been announced that the predicted displacements in the sun's spectrum have been found, and that the previous failures to find them have been explained. Also, more complete information is available relative to the eclipse observations, and it is generally conceded that they indicate a real deflection of light by the sun's gravitational field.

SIMPLE CHANGES WHICH EFFECT A MARKED IMPROVEMENT IN THE SCHREINER COLORIMETER.*

BY

C. W. DAVIS.

U. S. Bureau of Mines.

THOSE who have had occasion to use the Schreiner colorimeter will recall that the images of the comparison tubes are at some little distance apart so that the eye in determining an intensity match has to be moved from one image to the other across the interval between them. This not only makes an accurate comparison difficult, but also causes an eye-strain if many analyses are being run.

To eliminate these disagreeable features the following changes were made:

The open end of the chamber (through which the mirror is viewed) was closed by nailing a board across it in such a way that it was light-tight, but at the same time allowed the cover to slide. A hole one-fourth inch in diameter was bored in the centre of this closed end.

In changing the position of the comparison tubes so that the ten-inch inside tubes should be close together at the top and one inch apart at their lower ends, the supports of these inner tubes were taken off, bent at the proper angle, cut away on their inside edges and then replaced, close together, instead of at some little distance apart as they were formerly. The board above these supports was cut away, so that light could pass through the smaller tubes to the mirror without being obstructed. The supports of the outside comparison tubes were changed to conform to this arrangement by placing the outside supports farther apart and by replacing the common inner support by a wider one; all being so tapered that the outside tubes slipped over the smaller ones, the two sets being held parallel and concentric.

The reflector was removed and altered by cutting its mirror through the centre, parallel to its short edges, and by raising this cut intersection by placing under it and parallel to it a narrow strip

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* Published by permission of the Director of the U. S. Bureau of Mines. Communicated by Dr. R. B. Moore.

of wood or cardboard, the thickness of which was determined by trial.

The mirrors were attached temporarily to their frame with thumb tacks, as indicated above, using a strip of wood about three-sixteenths of an inch thick (to raise their tangent edges), and the reflector was replaced in the apparatus and turned so that the reflections of the comparison tubes on the mirrors could be best seen through the hole in the end of the chamber. When the images of the bottoms of the small tubes were seen as two distinct circles, one on each mirror, the strip under the mirrors was too thin; and when only a small part or none of the images of the bottoms of the tubes were visible, the strip was found to be too thick. The height of the intersection of the mirrors was adjusted so that a circle was formed, the right half being the image of one-half the bottom of the right inside tube, and the left half being the image of half of the left inside tube. The mirrors were then firmly attached to the frame by means of small screws.

Whenever the reflection on each mirror did not appear as a semicircle, the mirror intersection was not directly over the point of tangency of the comparison tubes, and was moved from right to left and back again until the right position was found. When the semicircles did not unite to form a circle, but one appeared higher than the other, the lower end of the inner comparison tube whose image seemed too high was pushed back until the circle was made perfect.

All new parts and all new surfaces were painted dead black.

Our Schreiner colorimeter, changed as described, has been greatly improved, so that it gives more satisfactory service and no longer causes noticeable eye-strain.[1]

GOLDEN, COL.,
    May, 1920.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

RECOMMENDED SPECIFICATIONS FOR BLACK PAINT, SEMI-PASTE AND READY-MIXED.[1]

[ABSTRACT.]

THIS specification for Black Paint, Semipaste and Ready-Mixed, is one of a series of specifications for paints and paint materials. It was prepared under the auspices of the Bureau of Standards with the coöperation of an interdepartmental committee organized for the purpose, and in coöperation with the Educational Bureau of the Paint Manufacturers' Association of the United States. Before final approval the specification was submitted to a large number of paint manufacturers whose suggestions were carefully considered.

The specification gives the required composition, methods of sampling, analytical methods for laboratory examination of both paste and ready-mixed paint, and describes acceptable methods of preparing the reagents to be used.

RECOMMENDED SPECIFICATION FOR OCHER, DRY AND PASTE.[2]

[ABSTRACT.]

THIS specification for Ocher, Dry and Paste, is one of a series of specifications for paints and paint materials. It was prepared under the auspices of the Bureau of Standards with the coöperation of an interdepartmental committee organized for the purpose, and in coöperation with the Educational Bureau of the Paint Manufacturers' Association of the United States. Before final approval, the specification was submitted to a large number of paint manufacturers whose suggestions were carefully considered.

The specification gives the required composition, methods of sampling, analytical methods for laboratory examination of both dry pigment and paste, and describes acceptable methods of preparing the reagents to be used.

RECOMMENDED SPECIFICATION FOR IRON-OXIDE AND IRON-HYDROXIDE PAINTS.[3]

[ABSTRACT.]

This specification for Iron-oxide and Iron-hydroxide Paints is one of a series of specifications for paints and paint materials. It was prepared under the auspices of the Bureau of Standards with the coöperation of an interdepartmental committee organized for the purpose, and in coöperation with the Educational Bureau of the Paint Manufacturers' Association of the United States. Before final approval the specification was submitted to a large number of paint manufacturers whose suggestions were carefully considered.

The specification gives the required composition, methods of sampling, analytical methods for laboratory examination of both paste and ready-mixed paint, and describes acceptable methods of preparing the reagents to be used.

INKS—THEIR COMPOSITION, MANUFACTURE AND METHODS OF TESTING.[4]

[ABSTRACT.]

This is a circular of general information on the subject of inks. The composition and manufacture are discussed only briefly, but the methods of testing which are in use at the Bureau of Standards are given in sufficient detail to enable any chemist to use them.

After a brief introduction on the history of ink, there are discussions of writing and copying inks, ink tablets and powders, marking, canceling, stamping, duplicating, and sympathetic inks.

The methods used for the laboratory examination of all but the last of these kinds of ink are next taken up. Under the analysis of writing inks, for instance, are the following headings: Total solids, ash, iron, sulphuric anhydride, tannin, dye, chromium, penetration, fluidity, keeping quality, and resistance to light and reagents. For the other kinds of ink there is not such a variety of tests necessary.

The circular closes with a short bibliography.

[3] Circular No. 93.
[4] Circular No. 95.

MEASUREMENT OF HYSTERESIS VALUES FROM HIGH MAGNETIZING FORCES.[5]

By W. L. Cheney.

[ABSTRACT.]

In a former paper, the writer described a method (a modification of the "isthmus method ") for measuring magnetic properties of ferro-magnetic materials. Very good results were obtained for normal induction but attempts to measure hysteresis values were not so successful, particularly in the case of the coercive force.

A study of the possible causes for the divergence of hysteresis data as compared with those obtained on standard apparatus has led the writer to believe that readings are affected by: (1) the residual magnetism in the core of the electromagnet after the primary circuit has been broken, (2) a change in the distribution of the flux about the specimen when the magnetizing force is changed from a high value to a low one, and (3) magnetic viscosity.

As a result of this study, a method for measuring the coercive force, which yields results comparing more favorably within the experimental error with data obtained on standard apparatus, has been developed. After repeated trials it was concluded that the method of measuring residual induction could not be improved upon.

The coercive forces and residual inductions from maximum magnetizing forces ranging from zero to 2500 gausses have been plotted against the latter as the independent variable. Both curves resemble in shape the intensity of magnetization curve.

MEASUREMENT OF PLASTICITY OF MORTARS AND PLASTERS.[6]

By Warren E. Emley.

[ABSTRACT.]

The Bureau has been endeavoring for many years to measure the plasticity of wall plasters. Many methods for making this measurement have been carefully investigated and successively abandoned, a little more information on the subject obtained through each failure.

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[5] Scientific Paper No. 383.

[6] Technologic Paper No. 169.

On the theory that plasticity depends upon the quantity of colloids in the material an unsuccessful attempt was made to measure this " colloidal content." The viscosity of a lime paste was found to give no indication of its plasticity. Measurement of the compressive strength of a green paste gives a figure for plasticity which meets the engineer's definition of the term, but does not meet that of the plasterer. The Atterbury method is not satisfactory because of the difficulty of determining the ends of the plastic range. Measurement of the rate of drying gives a good indication of the relative plasticities of materials when they are entirely different, but not when they are of similar nature. The Carson blotter test is excellent in the hands of an experienced operator, but the results cannot be recorded.

An instrument has been devised whereby the work done in spreading a plaster on a wall can be measured. A sample of the plaster is molded into cylindrical form on a porous plate. It is then pressed with a continuous screw motion against a stationary conical disk. The forces transmitted through the sample to this disk are measured. The porous base-plate acts as the undercoat on a wall to suck the water out of the sample; the disk acts as a trowel to spread the sample over the base-plate. The instrument enables one to measure the rate of drying of the plaster, the force required to spread it, and the thinness to which it can be spread. A proper correlation of these three factors leads to a definite expression of the degree of plasticity of the material.

LIME—ITS PROPERTIES AND USES.[7]

[ABSTRACT.]

This circular is intended to give general information as to what lime is, how it is made, and what it is used for.

Lime is made by heating limestone under certain conditions, whereby it is decomposed into an escaping gas, carbon dioxide, and a non-volatile residue, lime or quicklime. This lime, when treated with water, hydrates, or slakes. If water is used in great excess, a paste results; but if the amount is properly regulated, the hydration yields a dry powder, which is called hydrated lime.

Since natural limestones contain more or less magnesia, iron,

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[7] Circular No. 30 (2d Edition).

silica, etc., the quality of the lime will depend to some extent upon the nature and amount of these foreign materials.   It will also depend upon the way in which the stone is burned.

As a material for building construction, hydrated lime is better adapted than quicklime because it eliminates the labor usually required to do the slaking.   It is used very largely as a brick mortar, as an ingredient in concrete, and in the scratch and brown coats of plaster.   A particular grade of hydrated lime, noted for its plasticity, is sold as finishing lime and is used for the white coat of plaster.

Limestone, quicklime, and hydrated lime are used to a large extent as chemical reagents in the manufacture of other materials. In some of these industries the quality of the lime is of minor importance.   In others, the use of only one of the three forms of lime is satisfactory, and the quantity and kind of impurity which the lime may contain is definitely specified.

Eighteen of the most important chemical industries that use lime are enumerated.   Brief descriptions of these industries are given, showing why and how they use lime and the quality of lime which they require.

A list of the tests of lime which are usually made includes chemical analysis, rate of hydration, plasticity, sand-carrying capacity, time of set, compressive strength, proportion of waste, and fineness.

THE VARIATION OF RESIDUAL INDUCTION AND COERCIVE FORCE WITH MAGNETIZING FORCE.[s]

By R. L. Sanford and W. L. Cheney.

[ABSTRACT.]

This paper is a report of an investigation to ascertain whether or not analytical expressions similar to the reluctivity relationship of Kennelly correctly represent the variation of residual induction and coercive force with the maximum magnetizing force. Hysteresis measurements were made on a number of samples covering a wide range of materials using magnetizing forces up to 2500 gausses.   The relationships $H_m/B_r = a_1 + b_1 H_m$ and $H_m/H_c = a_2 + b_2 H_m$ were found to hold within the limits of the probable experimental error.

AN ELECTRON TUBE TRANSMITTER OF COMPLETELY MODULATED WAVES.[9]

By Lewis M. Hull.

[ABSTRACT.]

In order to utilize a radio frequency wave train of given power most effectively in a non-oscillating receiving system, it must be completely modulated at some suitable audio frequency. There are two possible methods of accomplishing this when an electron tube generator is used : The use of a direct voltage supply with a mechanical chopper or interrupter, and the use of audio frequency alternating e.m.f. The first method may be inconvenient if a large supply voltage is used, whereas the latter scheme may be so employed as to give excellent overall transmitter efficiency without the use of the high direct voltage. An alternator may be used to supply the power, with suitable transformers for both the filament and plate circuits.

A compact transmitting set of this type has been designed and built at the Bureau of Standards. A description of this set, with photographs and diagrams, is given. It has been used in fog-signalling tests, supplying 200 watts of power to an antenna having a resistance of 8 to 15 ohms, at wave-lengths of 500 to 1000 metres. Overall efficiency, from terminals of the 500-cycle alternator to the antenna, as high as 35 per cent. is obtained with this set. Transmission and reception tests have shown that the waves from this transmitter cannot be received, using a crystal detector, over as great distances as waves from a spark set of the same power, but for heterodyne reception it is practically the equivalent of a continuous wave transmitter of equal power output, and can be received over a somewhat smaller range with any non-oscillating detector.

RECOMMENDED SPECIFICATIONS FOR QUICKLIME AND HYDRATED LIME FOR USE IN THE COOKING OF RAGS FOR THE MANUFACTURE OF PAPER.[10]

[ABSTRACT.]

This is the first of a series of specifications for the lime used in various chemical industries. The new specification is based

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[9] Scientific Paper No. 381.
[10] Circular No. 96.

on a draft originally prepared at the Bureau of Standards. To assist in perfecting the specification, the Bureau of Standards called an interdepartmental conference of representatives of several bureaus most concerned. As revised, the specification has the unanimous approval of those concerned, including the National Lime Association and the Technical Association of the Pulp and Paper Industry. In addition to giving the percentage maxima or minima of the significant constitutents, detailed regulations are given for the packing and marking, and careful directions for the analytical methods used.

THE SPECTRO-PHOTOELECTRIC SENSITIVITY OF THALOFIDE.[11]

By W. W. Coblentz.

[ABSTRACT.]

EXPERIMENTAL data are given on the spectro-photoelectric sensitivity of Case's preparation of thallium-oxy-sulfide, thalofide, when exposed to thermal radiation of wave-lengths extending from 0.58μ to 3μ.

This substance has a wide unsymmetrical band of photosensitivity, which terminates abruptly at 1.2μ. The effect of temperature was investigated. The application of this substance to stellar radiometry is discussed.

A NEW MICROPHOTOMETER FOR PHOTOGRAPHIC DENSITIES.[12]

By W. J. Meggers and P. D. Foote.

[ABSTRACT.]

THE new microphotometer for measuring photographic densities is essentially the micropyrometer described in the Bulletin of the Bureau of Standards (Vol. 9, p. 475; 1913) except that a microscope of higher power is used. The photographic plate is mounted just below the objective of the microscope on a horizontal bed movable with a graduated screw and is illuminated beneath by an intense beam of light from a tungsten ribbon lamp.

[11] Scientific Paper No. 380.
[12] Scientific Paper No. 385.

Light transmitted by a small portion of the photographic plate, the image of which is adjacent to that of the tip of the pyrometer lamp, is matched with equal filament brightness by adjusting the current through the lamp. The ammeter readings are readily translated into measurements of photographic density. If the tip of the pyrometer lamp filament be regarded as a filar in the eyepiece, the relative positions or wave-lengths of spectral lines on a plate are measured at the same time that their photographic densities are measured.

An example of the use of this microphotometer for measuring wave-lengths and densities of spectral lines is given and it appears that the visually estimated intensities of such lines is a geometric series in accordance with Fechner's law.

Illustrations of this microphotometer's application to the measurement of energy distribution in a broad spectral line and to the measurement of spectral sensitivity of a photographic plate, are given.

Measurements of photographic density when the plate is illuminated by parallel light are found to be much larger than when the illumination is diffuse. This experience calls attention to the importance of specifying the character of the illumination when measurements are made on light transmission of diffusing media.

NOTES ON THE TESTING OF MAGNETIC COMPASSES.[13]
By R. L. Sanford.

[ABSTRACT.]

The work of the Bureau of Standards on magnetic compasses was undertaken in response to requests for information and coöperation from the War Department and the United States Shipping Board. It consisted of studies of the behavior of various types of compasses, the construction of special apparatus for testing purposes, and special investigations. The information thus obtained was utilized in the preparation of specifications for various types of compasses and also in the preparation of specifications for testing.

In the course of this investigation, certain facts concerning the general characteristics of campasses were brought out which

[13] Scientific Paper No. 382.

were considered to be of interest to users of magnetic compasses. This paper gives a brief discussion of the principal performance characteristics of magnetic compasses together with a description of some of the apparatus which is used at the Bureau for testing.

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PERMEABILITY OF RUBBER TO GASES.[14]

By J. D. Edwards and S. F. Pickering.

[ABSTRACT.]

CERTAIN of the factors which determine the permeability of rubber to gases have been investigated and the relative rates of penetration of a number of gases determined. The major findings may be summarized as follows:

1. The permeability of rubber compounds varies with the composition as would be expected. The aging of rubber films is accompanied by a decrease in permeability. A similar decrease may be affected by over-vulcanization. The rubber which shows a very low permeability for these reasons is usually very much deteriorated and frequently brittle so that it is a disadvantage from the standpoint of gas lighters.

2. The permeability to any gas is found to be directly proportional to its partial pressure provided the total pressure is constant. The variation of permeability with total pressure depends on the thickness of the rubber, the way in which it is supported, etc.

3. The permeability to hydrogen is inversely proportional to the thickness of the rubber. No other gas was tested in this respect.

4. The specific permeability to hydrogen at 25° C. of vulcanized rubber similar to the grade known as dental dam is about 20×10^{-6} c.c. per minute. This value varies somewhat with the age and chemical characteristics of the rubber.

5. The temperature coefficient of permeability is quite high. For example, in the tests at 100° C., the permeability to carbon dioxide or helium was about 17 times the rate at 0° C.; the permeability to hydrogen was about 22 times as great at 100° as at 0° C.

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[14] Scientific Paper No. 387.

6. The relative permeability of rubber to some common gases is shown in the following summary:

Gas	Relative Permeability Hydrogen = 1
Nitrogen	0.16
Air	0.22
Argon	0.26
Oxygen	0.45
Helium	0.65
Hydrogen	1.00
Carbon dioxide	2.9
Ammonia	8.0
Methyl chloride	18.5
Ethyl chloride	200.0

7. The permeability of rubber to water vapor is high—approximately 50 times the permeability to hydrogen. The value not having been determined with any precision is not included in the table above.

ATOMIC THEORY AND LOW VOLTAGE ARCS IN CÆSIUM VAPOR.[15]

By Paul D. Foote and W. F. Meggers.

[ABSTRACT.]

Theoretical.—On the basis of several possible theories of atomic structure it is shown that the *normal* operation of an arc below ionization might result in the excitation of a single line spectrum, a single series spectrum, or a group spectrum consisting of certain lines of different series. This latter conclusion follows from an extension of Bohr's theory. Thus if inelastic electronic-atomic impact occurred resulting in the ejection of an electron to the p th ring, the electron in returning to the n th ring or equilibrium may produce any combination of lines represented by inter orbit transitions within this range, the single line spectrum being a special case where $p = n + 1$.

A simple explanation is offered of fluorescence phenomena in vapors of the alkali metals.

A mechanism of absorption of radiation is described and the theory proposed by K. Compton that the ionization of an atom below the ionization potential may be explained by absorption

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[15] Scientific Paper No. 386.

of radiation arising in other atoms from e'ectronic-atomic impact
of insufficient energy to ionize is further discussed. This hypoth-
esis suggests that vapors of the alkali metals may be so stimulated
that the 1st and 2nd subordinate series lines, instead of the prin-
cipal series, tend to become absorption lines.

Experimental.—The cæsium spectrum was photographed for
various accelerating voltages from λ 3878 to λ 9208 by use of
dicyanin stained plates. The sensitivity of the plates was inves-
tigated by density measurements of the spectrum of a black body
having a known energy distribution. The general characteristics
of the plates were determined and all lines of the cæsium spec-
trum were reduced to an absolute sca'e of intensity by means of
density measurements made with a microphotometer and con-
sideration of the plate sensitivity. No evidence of group or
single series spectra could be obtained. Thus the ratio of inten-
sities of the first and second lines of the principal series, both of
which should appear in a single series spectrum or above 2.7
volts in a group spectrum, rapidly approaches infinity as the
accelerating potential in the arc is decreased. This ratio is 350
in a 7 volt arc, 2100 at 4 volts, 10,500 at 3.4 volts and as near
infinity as can be measured at 2.8 volts. Similarly the intensity
ratio of either $1.5\ s - 2\ p_1$ or $1.5\ s - 2p_2$ to any other line
approaches infinity at low voltage proving for the first time the
existence of a single line spectrum rather than a single series
or group spectrum; in the case of cæsium the doublet λ 8521
and λ 8943.

The doublet $1.5\ s - 2p$ is alone produced under excitation
of 1.5 to 3.9 volts accelerating field. The intensity of both of
these lines gradually increases approximately proportional to the
total number of electrons reaching the anode until the ionization
potential is reached. At this point a pronounced decrease in
intensity of these two lines occurs amounting to the fac-
tor one-third.

This decrease takes place at the voltage at which the com-
plete line spectrum is produced and is readily explainable on the
basis of Bohr's theory; in fact it affords a strong argument for
this theory. Thus the lines $1.5\ s - 2p_1$ are the result of inelastic
collision with electrons having velocities between 1.45 and 3.9
volts but as the latter voltage is exceeded electrons, which at a

slightly lower velocity would have given rise to $1.5s—2p_1$, now produce the complete series spectrum; and any line of the series $1.5s—mp$ where $m>2$ is necessarily excited at the sacrifice of $1.5\,s-2p_1$.

Above a certain voltage, the intensity of any line per unit number of electrons reaching the anode attains a saturation value, in agreement with the quantum hypothesis which requires that the number of quanta radiated be proportional to the number of collisions, and hence (approximately) to the number of electrons present.

Curves are given showing the relative intensities of the prominent cæsium lines at various voltages. The ratio of intensities of the components of the first doublet of the principal series $\lambda\,8521$ $\lambda\,8943$ is constant and equal to 1.5 from 1.5 volts to 120 volts.

The cæsium arc of the type employed does not rectify alternating current of 120 volts.

Sodium and potassium occurring as an impurity of the cæsium similarly exhibited the single line or doublet spectrum $1.5\,s-2\,p_1$ below their respective ionization potentials.

Only two types of inelastic impact between electrons and atoms of the alkali metal vapors occur, at potentials known as the resonance and ionization potentials and given by the quantum relation $\lambda\,\nu$ where $eV = \nu = 1.5\cdot s-2p_1$ and $\nu = 1.5\,s$.

Malaria Control From the Engineering Point of View.—Since malaria is spread by the *Anopheles* mosquito, the disease is best controlled by eradication of the mosquito, especially by elimination of its breeding places. According to W. G. STROMQUIST of the U. S. Public Health Service (*American Journal of Public Health,* 1920, x, 497–501) this end may be attained by drainage of the infected swamps, by oiling, or by means of fish. In drainage by ditches, a small V-shaped ditch should be cut in the bottom of the larger ditch. In oiling, the water surface frequently must be cleared. As to fish, the top water minnow, *Gambusia affinis,* is a deadly enemy of the mosquito, since it has a voracious appetite for the larvæ of the latter; this minnow must be protected against larger fish; and vegetation and other protection of the larvæ must be removed.

J. S. H.

NOTES FROM NELA RESEARCH LABORATORY.*

PURITY OF PALLADIUM USED IN GOLD-POINT PALLADIUM-POINT BRIGHTNESS RATIO.

By Edward P. Hyde and W. E. Forsythe.

In the *Astrophysical Journal* for May, 1920, data were pub-
lished on the gold-point palladium-point brightness ratio. At
that time no analysis had been made of the palladium used.
Inasmuch as the value for the melting point was somewhat
higher than that obtained by Day and Sosman in their work with
the nitrogen thermometer, a question was raised concerning the
purity of palladium. It has since been possible to test this point,
using two separate methods.. Through the courtesy of Doctor
Sosman, of the Geophysical Laboratory, a small sample of
the palladium used by Day and Sosman was obtained, making
possible a comparison of its melting point with that used in
this Laboratory.

Both samples were mounted between platinum wires, in the
manner described in the original paper, and alternate melts were
made in a platinum-wound black-body furnace. At the time
of melt the e.m.f. of the thermocouple was read and recorded.
The furnace was then held at this temperature and readings
made with the optical pyrometer. At least six readings were
made with the optical pyrometer for each melt. The average
results of twenty-six melts, twelve on one sample and fourteen
on the other, showed a difference between the melting-point
temperatures of the two samples of very close to one degree,
that furnished by the Geophysical Laboratory being higher. The
thermocouple and pyrometer readings agreed to within less than
this difference.

Small amounts of both samples were then sent to the Bureau
of Standards for a spectroscopic analysis. Both samples were
found to be nearly spectroscopically pure and showed only mi-
nute traces of silicon and lead. The sample from Nela Research
Laboratory contained more lead but less silicon than that from
the Geophysical Laboratory. They further reported that they

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* Communicated by the Director.

have not yet carried their investigations on the platinum family of metals far enough to give accurate quantitative results from spectral examination, but from experience with other alloys estimate that minute traces represent 0.001 to 0.01 per cent. in the cases of silicon, lead and gold.

The above tests show that there is but very little difference between the melting points of the palladium used by Day and Sosman and that previously used in this Laboratory, the indications being that the Geophysical Laboratory palladium has a slightly higher melting point.

Nela Research Laboratory,
    Cleveland, Ohio,
        July, 1920.

Mica. (*U. S. Geological Survey Press Bulletin No. 448*, June, 1920.)—Persons who are interested in deposits of mica should note the statement of the United States Geological Survey that only a large deposit of mica favorably located with regard to transportation and a grinding mill can be profitably worked solely as a source of scrap mica for grinding. Most mica mines must also yield good sheet mica to make the mining profitable. Mica to be of value as sheet must yield rectangles at least one and a half by two inches which must split easily and evenly, be free from cracks, markings, and fracture lines, and be reasonably free from specks or foreign mineral matter. The size stated is the smallest rectangular size which is salable as uncut sheet and the rough-trimmed mica sheet must be nearly twice as large to yield the rectangle stated. In order to be profitable most deposits must also contain some mica larger than one and a half by two inches.

If mica did not usually contain much foreign matter and did not have so many fissures and imperfections—cracks, markings and holes—there would be no difficulty in obtaining all the mica needed. But, in proportion to the mica mined there is only a very small percentage of sheet mica which when finally prepared is of the proper quality to be used in the industries.

Good sheet mica should be so flexible that a sheet a thousandth of an inch thick can readily be bent into a cylinder one-quarter of an inch in diameter without showing any cracking.

There is also a great variation in the hardness of mica, the Geological Survey recognizing seven different degrees of hardness. Mica is often erroneously called isinglass. This latter substance is a gelatin made of the air bladders of certain fish. The substance is soluble in water and burns readily, whereas mica is neither soluble nor combustible.

The production of the various kinds of mica in the United States ranges from 3000 to 5000 tons a year.

NOTES FROM THE RESEARCH LABORATORY
EASTMAN KODAK COMPANY.*

A METHOD AND INSTRUMENT FOR THE MEASUREMENT OF THE VISIBILITY OF OBJECTS.[1]

By L. A. Jones.

THIS paper is a report of the research work done during the war in an effort to determine the best method of painting a vessel in order to obtain low visibility. The theoretical aspect of the subject is considered at some length, and a description of the instrument built for the measurement of visibility is given. The factor used to express the weather conditions from the visibility standpoint (that is, the optical factors of the weather condition) is defined and is termed the " weather co-efficient." Curves showing the theoretical relation between visibility and the weather co-efficient and between visibility and the reflection factor of the object considered are given. Finally, curves plotted from actual measurements are compared with the theoretical curves, and fairly good agreement is shown.

THE IMPORTANCE OF THE NODAL POINTS IN LENS TESTING.[2]

By G. W. Moffitt.

THIS paper deals with the interpretation of the lens bench measurements when no collimator is used and when the object distance is limited.

In such cases the lens does not pivot on the second nodal point when lateral shift of the image is eliminated for small rotations of the nodal slide, but on a point which divides the separation of the nodal points into parts proportional to the magnification.

The complete formula for calculating the true focal length is

derived, and the conditions under which the ordinary approximate reduction is sufficiently accurate are discussed. An important conclusion is that the true equivalent focal length of any lens cannot be determined with certainty unless the apparent separation of the nodal points for the object distance actually used be determined.

For the correct reduction of field readings under the conditions of the test, additional formulæ are derived. Strictly speaking, one cannot deduce from such a set of readings what the field aberrations would be for a plane object at any distance from the lens. With respect to photographic distortion, there is no reduction that rigidly satisfies the problem in general, but an approximation sufficiently good for all practical purposes is obtainable in nearly all cases.

These refinements need not be taken into account in many cases, but it is always necessary to determine actually whether or not they may be ignored.

A METHOD FOR DETERMINING THE PHOTOGRAPHIC ABSORPTION OF LENSES.[3]

By G. W. Moffitt.

[ABSTRACT.]

THE axial photographic transmission co-efficient of a lens system for a given set of conditions will here be defined as the ratio of the light flux of photographic quality in the image of a small object on the axis of the system to the light flux of photographic quality that would reach the image were there no losses of any kind in transmission through the system other conditions remaining the same.

The method employed in determining this co-efficient involves the photographing of the lens image of a controlled circular source of approximate daylight quality and radiating according to the Lambert cosine law. Immediately after the completion of

the lens exposure strips of the plate on both sides and adjacent
to the lens image are impressed in a series of steps by direct action
of the same controlled source in such a manner that the exposure
in each step is continuous from beginning to end.   From the de-
veloped plate the ratio of the times of exposure for equal densities
in strips and image may be found.   This ratio, together with the
dimensions of the apparatus and the lens, gives sufficient data for
the determination of the transmission co-efficient of the lens for
light of photographic quality.   If dependable results are to be
obtained, care must be exercised in screening the plate from the
action of stray light, from nearby objects during the sensitometer
exposure and from barrel reflections during the lens exposure.
These later may easily be eliminated by using a stop considerably
less than the maximum, thereby eliminating the reflected light
from cell rings and lens edges.

The entire light flux directed towards the entrance pupil of a
lens system from a small element of source dS_o on, and perpendicu-
lar to, the axis of the system and radiating according to the
Lambert cosine law is

$$L = \pi I_0 dS_0 \sin^2 U$$

in which I_o is a constant characteristic of the source and U is the
angle subtended at the source by the radius of the entrance pupil.
Were there no losses this flux would ultimately be uniformly dis-
tributed in the image whose size is controlled by the magnification.
The flux density in the image (angle of incidence on plate disre-
garded) would therefore be

$$I_i = \frac{\pi I_0 \sin^2 U}{Y^2}$$

in which Y is the lateral magnification assumed positive for
real images.

Now if a photographic plate be directly exposed to the action
of radiation from a plane circular source parallel to the plate and
radiating according to the Lambert cosine law the flux density
at the plate will be

$$I_s = \frac{\pi I_0 R^2}{R^2 + l^2}$$

in which I_o is the constant characteristic of the source and R its
radius, and l is the perpendicular distance from the source to
the plate.

From these fundamental equations the expression for the transmission co-efficient may easily be found to be

$$T = \frac{t_s}{t_i} \cdot \frac{R^2 Y^2}{(R^2 + l^2)^s \sin^2 U} = \frac{t_s}{t_i} \cdot \frac{R^2}{R^2 + l^2} \left[Y^2 + \frac{[Y(f + d) + f]^2}{h^2} \right]$$

in which t_s/t_i is the ratio of exposure times for equal densities in strips and image, d is the distance from the first principal point of the lens system to the entrance pupil considered positive when the entrance pupil is farther away from the source than is the first principal point, and h is the radius of the pupil. The equivalent focal length of the system is represented by f and the other symbols have the meanings already stated. When the object distance is large Y is small and may become negligible in comparison with f, in which case the equation reduces to the following simple form

$$T = \frac{t_s}{t_i} \cdot \frac{4R^2 S^2}{R^2 + l^2}$$

in which S is the F-number of the lens.

Because of inherent irregularities in the photographic plate, quite a number of exposures must be made in order to arrive at a good average value of the transmission co-efficient. The preliminary results obtained have been found to be in good general agreement with those found by visual methods [4] as well as with values deduced from the theory of reflection and absorption.

Antagonistic Properties of Different Regions of the Spectrum. GUSTAVE LE BON. (*Comptes Rendus*, June 14, 1920.)—It has long been known that the ultra-red rays destroy phosphorescence, while rays belonging to the visible spectrum produce it. Let a zinc sulphide screen receive sunlight which has traversed a vessel containing sulphate of quinine. The screen does not phosphoresce. Now let a vessel with ammoniacal sulphate of copper be placed in front of the quinine solution. The screen no longer remains dark but glows. The following is the explanation. The quinine solution transmits all the rays which destroy phosphorescence and only a part of those rays which produce it. The copper sulphate solution absorbs the larger part of the destructive wavelengths, red and infra-red, while it transmits, as its color shows, the blue end of the spectrum which favors phosphorescence. This group of wave-length is not absorbed by the second solution, so it reaches the screen and produces its effect. G. F. S.

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[4] P. G. Nutting, *Astrophys. Jour.*, **40**, pp. 33–42, 1914; R. W. Cheshire, *Proc. Opt. Con.*, pp. 34–40, 1912.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

THE COMPOSITION OF OIL OF CHENOPODIUM FROM VARIOUS SOURCES.[1]

By E. K. Nelson.

[ABSTRACT.]

AN examination was made of the composition of oils of chenopodium derived from the plants cultivated in the producing district of Maryland, from the wild plants growing in Florida and the Eastern States, from plants grown in Java, and also of oils produced in the United States and used in Brazil for the treatment of hookworm disease.

The oils from cultivated domestic plants were found to comply with the requirements of the United States Pharmacopœia and to contain from 60 to 77 per cent. ascaridole. Oil distilled in Java from plants grown in that country was found to be similar to the oils of American origin. The oils distilled from wild plants proved to be similar in composition to the oils from cultivated plants, except that they were very deficient in ascaridole.

Emphasis is placed upon the necessity of carefully observing certain precautions in the distillation of chenopodium oil from the plant, to avoid the decomposition of the ascaridole by prolonged contact with steam or boiling water.

The terpenes of chenopodium oil were found to consist of a mixture of p-cymene, l-limonene, and probably a-terpinene.

INSECT POWDER.[2]

By C. C. McDonnell, R. C. Roark, and G. L. Keenan.

[ABSTRACT.]

THE fact that flowers of certain species of Pyrethrum possess the property of killing various insects was known to the people of eastern Europe more than a century ago. Since that time this knowledge has gradually spread, until insect powder is now a

* Communicated by the Chief of the Bureau.
[1] Published in *J. Am. Chem. Soc.,* **42** (1920), 1204.
[2] U. S. Dept. Agr. Bull. 824, issued June 3, 1920.

common household convenience. This powder owes its insecticidal activity to a mixture of acids and esters which first benumb and subsequently kill the insects brought into contact with it. While it is generally considered to be harmless to the higher animals, a number of cases where it has produced symptoms of a more or less serious nature are recorded.

In the enforcement of the Insecticide Act, insect powder has been found adulterated in a variety of ways.

Physiological, chemical, and microscopical methods which can be used satisfactorily in detecting adulteration with powdered stems, the most common form of sophistication, have not as yet been perfected to such a degree as to make an accurate quantitative determination possible. However, from the data obtained in the examination of hundreds of samples of genuine insect powder, of the materials used for its sophistication, and of commercial samples, the results of which are reported in this bulletin, a formula has been developed by which it is possible to determine in an insect powder the approximate amount of added Pyrethrum stems present.

SUMMARY OF BUREAU OF CHEMISTRY INVESTIGATIONS OF POISONING DUE TO RIPE OLIVES.[3]

By G. G. DeBord, R. B. Edmondson, and Charles Thom.

THE Bureau of Chemistry has examined 2161 commercial containers of ripe olives. Of these, 560 were glass and 1601 were tin. Cultural examination of 618 containers checked very closely with odor and appearance as determining the proper condition of the product.

Bacillus botulinus was found in material directly concerned in or taken from the pack that caused six groups of poisoning cases during the year. The organism belonged to Type A of Dickson and Burke. The toxic material examined was consistently sufficiently spoiled to be recognized as offensive by odor, especially at the time of opening the can. Emphasis is placed upon the responsibility of the person who opens a sealed container of food for determining its soundness before tasting it or serving it to others. Spoilage in any form condemns the product to destruction.

With reference to olives, the serious contaminations found were attributed to the practice of pre-fermenting the product by shipping and holding the olives in weak brine. The pre-fermentations encountered in different lots varied from a purely acid type to one pronouncedly putrefactive. All of these products were ultimately processed, and carried their contamination over into the canned product, making sterilization difficult.

SOME PROTEINS FROM THE GEORGIA VELVET BEAN, STIZO-LOBIUM DEERINGIANUM.[4]

By Carl O. Johns and Henry C. Waterman.

[ABSTRACT.]

The Georgia velvet bean contains 23.6 per cent. of protein ($N \times 6.25$). Salt solutions of optimum concentrations (3 per cent.) extract about 15 per cent. of protein. From such solutions two globulins, designated the α- and β-globulins, and an albumin may be separated, the first two by fractionation with ammonium sulphate and the last by coagulation from extracts from which the globulins have been precipitated by prolonged dialysis.

The proteins are sharply distinguished by their different sulphur and nitrogen content, by differences in the percentages of the basic amino acids, as determined by Van Slyke's method, and by the fact that the β-globulin does not give the Hopkins-Cole reaction for tryptophane. The latter observation is of particular interest inasmuch as this amino acid has been found in all seed globulins heretofore tested. Both the α-globulin and the albumin from the Georgia velvet bean contain tryptophane.

THE CHEMICAL COMPOSITION OF COTTONSEED OIL.[5]

By George S. Jamieson and Walter F. Baughman.

[ABSTRACT.]

An investigation was undertaken to determine quantitatively the fatty acids occurring in measurable amounts in cottonseed oil, the composition of which has been a subject of controversy for many years. Cold pressed oil from Sea Island cotton, obtained by means of the expeller, was used for this study. It contained

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[4] Published in *J. Biol. Chem.*, **42** (1920), 59.
[5] Published in *J. Am. Chem. Soc.*, **42** (1920), 1197.

23 per cent. of saturated acids and 72.5 per cent. of unsaturated acids as determined by the lead-salt-ether method. The iodine value (Hanus) of the unsaturated acids was 142.2, the saponification number was 199.4, and the mean molecular weight was 281.3.

In addition to the separation and identification of stearic and arachidic acids, a small amount of myristic acid was found which has not been previously reported as occurring in cottonseed oil.

The following table gives the percentages of the acids found from which the corresponding glycerides were calculated:

Acid.	Per cent in Original Oil Acids.	Per cent in Original Oil Glycerides.
Myristic	0.32	0.34
Palmitic	19.10	20.04
Stearic	1.90	1.96
Arachidic	.56	.58
Oleic	33.15	35.17
Linolic	39.35	41.74

Galvanomagnetic Effect Parallel to the Lines of Force and Perpendicular to the Current. La Rosa and A. Sellerio. (*Comptes Rendus,* June 14, 1920.)—If an electric current flows along a sheet of bismuth, the ends of two wires joined to a galvanometer may be put in contact with two points on the bismuth so located that they are at the same potential. In this case no current flows through the instrument. If, now, a strong magnetic field is applied with its lines of force at right angles to the sheet of bismuth, a current shows itself in the galvanometer. The magnetic field has distorted the lines of flow of the current (Hall effect).

The two experimenters placed a cylinder of bismuth between the poles of a Weiss electromagnet with its axis parallel to the lines of force. A current was sent from one side of the cylinder to the other and the ends of the wires from the galvanometer were soldered to points on the end of the cylinder which were at the same potential, when the magnetic field was absent. When the field was excited there was a permanent deflection of the galvanometer, which was reversed in direction when the field was reversed. The deflections in the directions were by no means alike in size. The authors conjecture that there are two effects superimposed, one of which reverses with the field while the other does not. The difference between this new phenomenon and the Hall effect is in this, that in the latter the effect is perpendicular to the direction of the current, while in the newly discovered effect it is manifested along the magnetic lines of force.

G. F. S.

NOTES FROM THE U. S. BUREAU OF MINES.*

ACCIDENT PREVENTION IN THE MINES OF BUTTE, MONTANA.

By Daniel Harrington.

AN investigation of the health and safety conditions in the Butte district has been conducted by the Bureau in coöperation with the U. S. Public Health Service. In Butte the problem of safeguarding from accidents has been a difficult one, because of the great depth and extent of the mines, the large labor turn-over, and during the war, the intensity at which the mines were worked.

Some of the companies have expended much money and effort in developing safety organizations and in safety and wel-fare work. Hence this investigation, covering one of the most important metal-mining centres, where safety organizations and work have been brought to a high plane by some of the companies, is of special interest. It was found that the results obtained were commensurate with the effort expended, not only in decrease of accidents, but in the large financial saving to the companies. For example, one large company specializing in fire prevention had no serious losses from fire; another specializing in prevention of injuries had a comparatively low accident rate, and another specializing in ventilation, has converted a " hot " mine into one of the most comfortable and sanitary in the district.

Technical Paper 229, " Accident Prevention in the Mines of Butte, Mont.," recently issued by the Bureau, is a detailed report on the investigation.

EFFECTS OF GASOLINE REMOVAL ON HEATING VALUE OF NATURAL GAS.

By Donald B. Dow.

THE question as to the loss of heating value of natural gas through the removal of the gasoline vapor that the gas contains, has caused much controversy, in which the public in general and

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* Communicated by the Director.

legislative bodies and public ultilities commissions have taken part. Notwithstanding the several sources of information available, the general understanding in regard to this question remains unsettled.

In the hope that this uncertainty may be removed, the Bureau of Mines has made a comprehensive investigation of the problem through its petroleum station at Bartlesville, Okla. The natural gas examined included gas being treated at gasoline plants in many different fields; not only " dry " gas treated by absorption, but also rich " casing-head " gas treated by this method, in order that definite information might be available as to the effect of recovering gasoline from natural gas of varying richness and from different localities.

In general, the decrease in heating value of natural gas from removal of the gasoline vapor is overestimated. The loss in the B. t.u. value of the " dry gas " ordinarily supplied to the domestic consumer was found to be about 2 per cent. after the gasoline vapor had been removed, but for " casing-head " gas, which rarely reaches the domestic consumer, the percentage loss is larger. As the gasoline vapor in natural gas is usually accompanied by proportionate amounts of other constitutents of high heating value, a high gasoline content usually indicates a gas of high heating value even after the gasoline has been removed.

The detailed results of the investigation are presented in Technical Paper 253.

USE OF STENCHES AS A WARNING IN MINES.
By S. H. Katz.

An investigation by the Bureau on the use of stenches in the compressed air lines as a means of warning miners in the event of imminent danger, has shown that the method is of great practical value. Stenches were tried in the Bureau's laboratories and in the experimental mine, and later large-scale tests were made in a number of metal mines. Of the chemicals tried, the best were butyl mercaptan, ethyl mercaptan, butyric acid and amyl acetate.

Technical Paper 244, " Use of Stenches as a Warning in Mines," by S. H. Katz, V. C. Allison, and W. L. Egy, gives the results in detail.

PHYSIOLOGICAL EFFECTS OF CO.

Plans are being made to extend work on effects of CO in small quantities on men in confined spaces, being conducted by the Bureau at Yale University for the New York and New Jersey State Tunnel Commission, to include a general study of effects of CO and associated gases on men working in mines and metallurgical plants.

OIL-SHALE COMPOSITION.

Microscopic examination by Dr. R. Thiessen at the Pittsburgh laboratory of the Bureau, of oil shales from Illinois, Utah, Colorado, and Nevada, indicate that the oil distilled from the shale is not present in the shale as oil, but as original plant matter or as degradation products of plants.

A quantitative method for the determination of vitamine has been devised by Roger J. Williams (*Journal of Biological Chemistry*, 1920, xlii, 259–265). The method is for the quantitative determination of the vitamine which prevents beriberi. A synthetic medium is prepared, each litre of which contains 20 grams cane sugar, 3 grams ammonium sulphate, 2 grams monopotassium phosphate, 1.5 grams asparagine, 0.25 gram calcium chloride, and 0.25 gram magnesium sulphate. One hundred c.c. of this medium is diluted to a volume of 110 c.c., sterilized, inoculated with a suspension of fresh compressed yeast in sterile water containing 0.3 milligram of yeast and having a volume of 1 c.c. The culture is incubated for eighteen hours at a temperature of 30° C.; growth is stopped by addition of formaldehyde solution; the yeast is collected by filtration of the culture through a weighed Gooch crucible, washed with water and with alcohol, dried for two hours at a temperature of 103° C., and finally weighed. This is the control experiment, and the yield of yeast is approximately 2.5 milligrams. At the same time, 100 c.c. of the synthetic medium and a definite volume of an extract representing a definite weight of the substance to be tested for vitamine are mixed, diluted to a volume of 110 c.c., sterilized, sown with the yeast as already described, and then treated in exactly the same manner as the control experiment. The yield of yeast above that in the control is a measure of the vitamine content of the substance tested. " The ' vitamine number ' of a material may be defined as the number of milligrams of yeast produced by the addition of its extract minus that produced in a control solution, under given conditions and within certain limits, computed to 1 gram of the original material tested."

J. S. H.

Scientific problems of cold storage industries are discussed by W. B. HARDY in the *American Society of Refrigerating Engineers Journal,* 1919, vi, 201–208. One problem is the storage of fruits and vegetables which are actually alive when harvested. If they are to be preserved in any semblance of their normal selves, they must be kept alive. While their duration of life may be lengthened, no method yet tried will do more than double their natural life. The duration of life may be increased (1) by use of cold storage which retards the chemical processes in the living matter, or (2) by controlling the oxygen supply and thereby decreasing the total respiration. However, interference with the normal respiration may so modify the chemical changes in fruit as to render the latter unfit for food; thus strawberries preserved in this manner may produce amyl alcohol. Another problem is the freezing of beef for cold storage in such a manner that it does not drip on thawing. When beef is frozen in air by the usual procedure, the relation of the solid and liquid constituents of the muscle is so altered that a considerable amount of liquid drips from the carcass on thawing. During freezing the solid constituents are first separated from the liquid and the latter is then solidified. Now, if beef muscle be frozen sufficiently rapidly, this separation of the solids from the liquid does not occur, and dripping does not take place on thawing; the normal character of the muscle is also preserved. For rapid freezing the medium surrounding the beef must be denser than air, and must have a high specific heat. Satisfactory results have been obtained in laboratory experiments, and the process must now be developed on a commercial scale. Other problems which may be mentioned are: The measurement of heat flow through insulating materials; the determination of humidity at low temperatures; the construction of insulated lighters to convey produce from ships to storage plants; and the relation of the fats and oils of stored perishables to changes in their flavor.   J. S. H.

Detection of Coal-tar Dyes in Butter and Oleomargarine.— G. VAN B. GILMOUR (*Analyst,* 1920, xlv, 173) has devised the following test: The fat is separated from the melted sample by filtration; the temperature must not exceed 100° C. Approximately 1 c.c. of the fat is placed in a test tube which is then placed in an oil bath. The temperature of the bath is raised to approximately 185° C. The test tube is occasionally removed, shaken, and replaced in the bath. If the fat contains only vegetable butter colors or the natural pigment of butter, it will become colorless within ten minutes at a temperature of 180° to 190° C. If the fat remains colored, coal-tar dye is present. However, butter-fat separated at a temperature above 100° C. will not become colorless on heating.

J. S. H.

THE FRANKLIN INSTITUTE.

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BOOK NOTICES.

TRAITÉ DE LA LUMIÈRE, PAR CHRISTIAN HUYGHENS. 12mo., 153 pages, contents and 74 illustrations. Paris, Gauthier-Villars et Cie, 1920. Price, 3f 60, in paper.

This is the first volume of a series of reprints of epoch-making publications of scientists of earlier days, the title of the series being " Les Maitres de la Pensée Scientifique." The general editorial supervision is by Maurice Solovine. The reprint is preceded by an editorial note summarizing the life and work of Huyghens, from which we learn that he was born at The Hague in 1629 and died in 1695. His father was a statesman and poet. Christian's progress in education was rapid, and at the age of sixteen he wrote a paper on a mathematical subject which was commended by Descartes.

The particular paper reprinted in this volume was published in 1690, in which also appeared his " Discours sur la cause de la Pesanteur." The prospectus of the series gives a long list of essays by famous scientists, mostly physicists and mathematicians and principally of Continental Europe, but including the works of Newton, Faraday, Young and Herschel. Some biologic essays are listed. A perusal of memoirs of earlier workers is of interest and advantage to the student and should be encouraged by teachers. One feels often, in reading the essays of scientists or philosophers of several centuries ago, the force of Chaucer's lines:

> " For out of the old fieldes as men saithe,
> Cometh al this new corne fro yere to yere ;
> So out of old bookes in good faithe,
> Cometh al this new science that men lere."
>
> HENRY LEFFMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS. Report No. 63. Results of Tests on Radiators for Aircraft Engines. Preprint from Fifth Annual Report. 34 pages, illustrations, diagrams. Quarto. Washington, Government Printing Office, 1920. The work is divided into two parts.

Part I shows in tables and curves the results of measurements of geometrical characteristics of 59 types of radiators, together with such physical properties as heat transfer, head resistance, air flow through the core, power absorbed, and figure of merit. In most cases the properties are shown for speeds running up to 120 miles per hour.

The terms used in describing the radiators and their performance are defined, the more evident relations between the properties and characteristics are stated, and applications of the results to the design of a radiator are pointed out.

It is shown that the most efficient type of radiator tested, for use at high speeds and mounted in " unobstructed " positions on the aircraft, is one whose water tubes are flat hollow plates, placed edgewise to the air stream, and continuous from front to rear of the radiator.

Part II shows in curves the pressure heads required to produce given rates of flow of water in twelve sections of radiator, each of a different type, briefly described and shown in photographs, but each with a core

eight inches square. The methods used in the tests and in computation are stated in detail, and a method is developed for estimating, by the use of twelve sets of auxiliary curves, the pressure head required for a given rate of water flow in each type of radiator, when of any size, on the assumption that losses of head at inlet and outlet of the water tubes are negligible in comparison with the resistance in the tubes of the eight-inch sections.

Report No. 65, The Kiln Drying of Woods for Airplanes. Preprint from Fifth Annual Report. 31 pages, illustrations, plates. Quarto. Washington, Government Printing Office, 1920.

The exigencies of the war and scarcity of air dried material necessitated kiln drying stock immediately from the green condition. Exhaustive experiments and tests made by the Forest Products Laboratory during the last ten years have established the fact that properly kiln dried wood is just as strong, tough and stiff as the best air dried material. Douglas fir wing beams may be dried in 18 to 24 days. To air dry the same material requires 12 to 18 months. Hardwood propeller stock, which requires a year or more for air drying, may be satisfactorily kiln dried in 30 days. The important qualities of dried wood are freedom from checks, honeycombing, or casehardening; uniform moisture distribution; maximum strength and toughness; freedom from collapse and warping; and minimum shrinkage.

The microscopic structure of wood is briefly described; also the way in which moisture is contained in wood, and the properties and behavior of wood upon removal of moisture.

Methods of controlling the circulation, humidity and temperature in the various kilns are discussed; also the use of instruments for determining actual conditions within the kiln.

The method of piling the lumber within the kiln has much to do with the factors of circulation and control of conditions. In order to know what is taking place, a suitable method of sampling and testing the material during the progress of drying must be instituted, and definite records kept of the process. These points are fully discussed. Methods for removal of casehardening and prevention of mold are described.

The appendix contains the Signal Corps specifications for kiln drying airplane stock, a constant dew point schedule for Douglas fir, spruce and similar woods, and a brief description of the Forest Service water spray dry kiln.

Report No. 73. The Design of Wind Tunnels and Wind Tunnel Propellers. Preprint from Fifth Annual Report. 24 pages, illustrations, diagrams. Quarto. Washington, Government Printing Office, 1920.

This report is devoted to the study of theory of wind tunnels and wind tunnel propellers, and to an analysis of present-day practice in wind tunnel propeller design. The application of the blade element method of design is also discussed. The conclusion is reached that large tunnels giving a moderate air speed are in general preferable to small tunnels of very high speed. The losses in the exit cone are charted in accordance with Eiffel's investigations, a set of curves being constructed

which permit the immediate determination of the approximate efficiency of a projected design of tunnel.

The concluding portion of the report deals with model wind tunnel experiments, including both the efficiency of the tunnels and the regularity of distribution of air-flow across the section. The conclusion is reached that the ·Eiffel type of tunnel is much inferior to one with a continuous closed tube.

Report No. 77. Preprint from Fifth Annual Report. 41 pages, illustrations, plates. Quarto. Washington, Government Printing Office, 1920.

The purpose of this report is to describe the work done by Mr. H. F. Parker, in the development of a wing permitting of variation of the camber and having wider range of usefulness than is possible at a single section. The Parker rib contains two sets of diagonal wires, one of which is normally slack, and a considerable motion is possible between the extreme positions where the two sets of diagonals become taut. The report describes statical tests for strength on ribs constructed in this manner. These tests were very satisfactory, the ribs comparing favorably in strength with those built up rigidly in the ordinary way. A series of aerodynamic tests on sections of the various forms which the Parker wing would assume in passing from one extreme position to the other are also included, the wings having been tested as monoplanes and in biplane and triplane combinations of various types. The maximum absolute coefficient for the Parker wing at its high-lift setting was .77, while the minimum drag coefficient for a wing of the form which the Parker wing has with the other set of diagonals taut (the form then being approximately symmetrical about a centre line) was .007. The ratio of maximum lift to minimum drag coefficient was, therefore, exceptionally high.

Report No. 80. Stability of the Parachute and Helicopter. Preprint from Fifth Annual Report. 11 pages, illustrations. Quarto. Washington, Government Printing Office, 1920.

This report deals with the mathematical theory of the stability of bodies normally travelling vertically, especially with aircraft symmetrical about a vertical axis, as is the case with the ordinary parachute. The treatment is based on the method of Bryan and Brodetsky. It is pointed out that the parachute may have a compound oscillation of a complex form, and some of these oscillations are illustrated. The conditions of stability are deduced, and rules and a chart are given which make it possible to predict the degree of stability for any parachute for which the resistance and rotary derivatives and other characteristics have been determined by wind tunnel test or otherwise.

Copies of the above reports may be obtained from the Committee.

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National Advisory Committee for Aeronautics: Fourth Annual Report, 1918. 654 pages, illustrations, plates. Quarto. Technical Notes No. 5,

Relation of Rib Spacing to Stress in Wing Planes, by A. F. Zahm. 5 pages, illustrations, plate. No. 6, Static Testing and Proposed Standard Specifications, by E. P. Warner. 17 pages, illustrations. No. 7, Notes on the Design of Supercharged and Overdimensioned Aircraft Engines, by Schwager. 6 pages, diagrams. Washington, Government Printing Office, 1920.

Hydration as an Explanation of the Neutral Salt Effect, by John Arthur Wilson. 6 pages, illustrations, 8vo. (Reprinted from the *Journal of the American Chemical Society,* April, 1920.)

The Railroad Situation. The Duty of Every Newspaper: A Letter to Members of the Southern Newspaper Publishers' Association, by Victor H. Hanson. 11 pages, 8vo. New York, Association of Railway Executives, 1920.

Missouri School of Mines: Catalogue, 1919–1920. 164 pages, illustrations, 8vo. War Records. 88 pages, plate, 8vo. Rolla University, 1920.

U. S. Bureau of Mines: Bulletin 112. Mining and Preparing Domestic Graphite for Crucible Use, by George D. Dub and Frederick G. Moses, with a chapter on Methods of Analysis Used by the Bureau of Mines, by G. B. Taylor and W. A. Selvig. 80 pages, illustrations, plates, 8vo. Monthly Statement of Mine Fatalities in the United States, April, 1920, by W. W. Adams. 8 pages, 8vo. Washington, Government Printing Office, 1920.

True Tanning Value of Vegetable Tanning Materials, by John Arthur Wilson and Erwin J. Kern. 12 pages, illustrations, 8vo. (Reprinted from the *Journal of Industrial and Engineering Chemistry,* May, 1920.)

Present Status of the Refrigerating Industry in Russia.—According to NICHOLAI BORODIN (*American Society of Refrigerating Engineers Journal,* 1919, vi, 190–195), at the beginning of the World War, Russia contained 343 plants provided with mechanical refrigeration, in addition to numerous large cold storages for butter and fish which were refrigerated by means of ice. The total mechanical refrigeration amounted to approximately 28,000,000 normal calories. During the war, the cold storage plants were increased in number. Seventeen slaughter houses were constructed; each had a daily capacity of 150 head of horned cattle, and was provided with the means of freezing and storing the meat; two of these houses have been destroyed by fire. The army also constructed seven cold storage plants each with a capacity of 30,000 pounds of meat, and four plants with a refrigeration capacity of about 800,000 calories each. Of the latter plants, each was attached to a slaughter house intended to handle 500 head of cattle as well as some sheep; machinery for them was obtained from breweries. When political and economic conditions in Russia become settled a great demand will exist in that country for refrigerating machinery, cold storage equipment, and refrigerator cars.

J. S. H.

CURRENT TOPICS.

Carbon Dioxide Content of Milk.—Lucius L. Van Slyke and Richard F. Keeler of the New York Agricultural Experiment Station at Geneva have made a research on " The Carbon Dioxide Content as a Basis for Distinguishing Heated from Unheated Milk " (*Journal of Biological Chemistry*, 1920, xlii, 41-45). Normal milk in the udder has an average carbon dioxide content of approximately 10 per cent. by volume. Immediately after the milk is drawn from the udder, either by hand or by a milking machine, its carbon dioxide content usualy lies between 4 and 4.5 per cent. by volume. When fresh milk was allowed to stand, its carbon dioxide content decreased and attained a minimum value of 3 per cent. by volume from twenty to forty hours after milking. Agitation, such as milk may undergo on the farm and during marketing, had little or no effect in reducing the per cent. of carbon dioxide in the milk. After pasteurization by the flash system or by heating for thirty minutes at either 62° or 78° C., milk seldom contained more than 2.5 per cent. carbon dioxide by volume, and usually contained less. " Therefore, it appears safe, in general, to assume that milk containing less than 2.5 or 3 per cent. of carbon dioxide by volume has been heated to the temperature of pasteurization."

J. S. H.

Tests of Auxiliary Condensers. C. Waldie Cairns and J. Morrow. (*North-East Coast Institution of Engineers and Shipbuilders*, May 17, 1920.)—The paper is based on a report to the Council by the authors, on tests carried out by them for the purpose of determining the relative performances of certain auxiliary condensers for use on board ship. Four condensers were tested, *viz.*, two of "Contraflo" type, one of cylindrical, and one pear-shaped.

The particular condensers are described in detail. The experiments conducted are described and comparative tables of the results from the tests made upon each condenser are given. A statement of conclusions from these results completes the report.

The Existence of Homogeneous Groups of Large Ions. O. Blackwood. (*Proc. Nat. Acad. Sciences*, May, 1920.)—When distilled water is sprayed large ions are produced, whose exact nature is as yet unknown. It is maintained by some that these ions are of only a few definite sizes.

This was investigated by studying the flow of an air stream carrying such ions through the space between two concentric cylinders, between which there was a difference of electrical po-

tential. The electric field imparts to the charged ions a lateral motion and hence the strength of the ionic currents varies with difference of potential maintained. The connection between these quantities was found by experiment and the results were compared with the results calculated on the supposition that there were only three kinds of ions present. The actual and the theoretical results were very different from which the conclusion is drawn. " It has now been shown that, contrary to the findings of other observers, a series of widely separated, well-defined mobility groups does not exist in the ionization from spray. Their hypothesis that the large ion is a complex cluster of stable water molecules may consequently be abandoned in favor of the simpler conception of J. J. Thomson and others, who have pictured the large ion as merely a charged globule of water having a radius of equilibrium which is a function of the humidity of the air."

G. F. S.

Wireless Telegraphy in the British Army. (*Electrician,* June 25, 1920.)—Instruments used at Woolwich are reported to transmit more than 2000 words per minute. A range of 250 miles with an accuracy of one degree of arc is claimed for a new miniature, revolving direction-finder. Moreover, an instrument has been devised for transforming ground line telegraphic signals into wireless with a normal speed of 450 words per minute.

G. F. S.

Activities in the National Physical Laboratory Near London. (*Electrician,* June 25, 1920.)—The laboratories have resumed their pre-war appearance and no parts are closed to the public.

A study of the heating of underground electrical cables has been in progress for several years. It has been found that the thermal conductivity of the dielectric in paper-insulated cables varies considerably with the make. This difference in turn affects the permissible load, since the slower the rate of cooling the higher the temperature becomes. The quantity of moisture in the ground surrounding the cable is another important factor. The drier the ground the slower the dissipation of heat and the greater the rise of temperature in the cable.

For the tests a motor generator giving 5000 amperes at 6 volts is used. To keep the current constant to one-tenth of 1 per cent. this device was employed. The current passes through a resistance whose P.D. is balanced by a potentiometer. In one of the lines to this instrument is a galvanometer reflecting a spot of light upon a scale at the two ends of which are two selenium cells forming two arms of a Wheatstone Bridge. From their junction is connected a polarized relay. When the main current is of the desired strength, the galvanometer does not deflect. When, however, the current changes, the galvanometer deflects and throws

its spot of light on one or other of the selenium cells, thereby
changing the resistance of the latter. This upsets the balance in
the bridge and causes a current through the relay, which oper-
ates other relays varying resistance in circuit with the shunt cir-
cuit of the generator. If the main current is too large the spot of
light moves in one direction; if it is too small the direction of
deflection is in the opposite direction. Different selenium cells
receive the light spot in the two cases and the current in the relay
has its direction determined accordingly and a different modifi-
cation of resistance is brought about. This is another of the
steadily growing applications of selenium.

G. F. S.

Death of the Italian Physicist, Augusto Righi. (*Revue Sci-
entifique,* June 26, 1920.)—At the age of seventy this distinguished
physicist recently passed away. Among his contributions to
science are these: The discovery that bismuth in a magnetic field
suffers a change of electrical resistance, the confirmation of quali-
ties common to luminous radiation and to electrical waves; inves-
tigations of the phenomena of the electrical spark, especially of
the spark in the magnetic field, and a critique of the Michelson-
Morley experiment on which is based the modern theory of rela-
tivity. It was in his laboratory that Marconi made his early ex-
periments on wireless telegraphy. In announcing the death of
Professor Righi to the Paris Academy of Sciences the President,
Henri Deslandres, said: " Professor Righi is one of the foremost
physicists of our age. He directed his activities toward the most
varied subjects and his name is connected with all the great
questions of natural philosophy which have arisen in recent years.
On those points which he approached he left his profound and
original impress."

The chair of Physics in Bologna was held for many years by
this worthy successor to the Italian tradition in this science
established by Galileo.

G. F. S.

**The Functions of Intensity and Phase in the Binaural Loca-
tion of Pure Tones.** G. W. Stewart. (*Proc. Nat. Acad. Sci.,*
April, 1920.)—The two ears of a person are in general at different
distances from the source of sound and hence receive sound waves
of different intensities. It is obvious to regard this difference at
the ears as a possible factor in locating the source of sound. After
careful experimental examination Professor Stewart reaches this
somewhat surprising conclusion: " The intensity effect cannot
account for the ability to locate sounds. It does not appear to be
even an important factor." He finds, however, that the difference
of phase at the two ears is the controlling factor in forming the
judgment of location, at least in the case of pure tones, such as

those of a tuning fork. The ears in some way perceive a difference
between sound wave and another of the same pitch which is
ahead or behind the first in its cycle of motion. This ability to
notice phase difference ceases when the frequency of the sound
is from 1200 to 1500 double vibrations per second. The results
just summarized are not in accord with the views generally pre-
sented in psychological literature.

G. F. S.

The Most Powerful Gas Engine in the World. (*La Nature,*
June 19, 1920.)—This distinction is claimed for an engine made
by the Cockerill Society in Liege, Belgium. In August, 1914, it
was in process of erection. The Germans after the capture of the
city allowed it to be put into operation and, when they were
assured of its success, took it from its owners and sent it into
Germany, to Duisburg, where it was running at the time of the
Armistice. It was then sent back to Liege, where it was installed
for the second time, with the addition of some improvements. It
develops 8000 horsepower. The cylinders, four in number, are 1.3 m.
in diameter, 1.5 m. stroke, 94 r.p.m. The heat of the gases coming
from the engine is used to generate steam for a turbine.

G. F. S.

Observatory of Terrestrial Magnetism in Western Australia.
J. A. FLEMING and W. F. WALLIS. (*Ter. Magnetism,* March,
1920.)—Owing to the energy and well-laid plans of Dr. L. A.
Bauer the general magnetic survey of the earth is within sight of
completion. The next step in the campaign of the Department of
Terrestrial Magnetism of the Carnegie Institute of Washington
is the promotion of additional observatories in various parts of the
earth. The dearth of such observatories in the southern hemi-
sphere led to a search for a suitable site in Australia. The place
finally selected is 12 miles west of Watheroo on the Midland Rail-
way, 132 miles from Perth. The Government of Western Aus-
tralia generously donated 240 acres of land for the observatory.

Several lines of work will eventually be conducted at the in-
stitution and for each certain definite qualities are needed in
the site.

A. Terrestrial Magnetism.
   a. Freedom from sources of artificial magnetic disturbances.
   b. Uniform distribution of magnetism.
   c. Reasonably dry climate.
B. Atmospheric Electricity.
   a. Remoteness from towns.
   b. Nearness to sea level.
   c. Presence of a flat space near observatory.
   d. Absence of trees, shrubs, etc.
   e. Distance to sea not greater than 50 miles.

C. Earth Currents.
   a. Possibility of laying two cables at right angles to each
        other for lengths of ten miles.
D. Solar Constant Observations.
   a. Dry climate and small rain fall.
   b. Location at some distance from sea coast.
E. General, Meteorological, Seismological, and Office Routine.
   a. Accessibility for supplies and mail.
   b. Good water for photographic work.
   c. Telegraph or telephone connections.
   d. Comfort of the observers.

Not all types of work have been provided for up to the present. Observations in terrestrial magnetism began on January 1, 1919, and meteorological data also are obtained.

G. F. S.

Petroleum in France and Her Colonies. (*La Nature*, May 22, 1920.)—Since the scientifically executed destruction of the coal mines in northern France by the Germans, the question of fuel has become a vital one in this country. Now she is entirely dependent on importation for her supply of oil. Even this is precarious owing to the increasing use of liquid fuel and of gasoline. To provide for the future a search is being made for sources of petroleum within her own territory. In several parts of France promising indications of oil have been found. In Isere sandstone 32 inches thick is impregnated with petroleum. Already in Algeria oil is produced on a small commercial scale. The same is true in Tunis, and there is some reason to believe that Madagascar and Indo-China may have oil beds.

G. F. S.

The Commercial Application of Electrical Osmosis. J. S. HIGHFIELD, W. R. ORMANDY, and D. NORTHALL-LAURIE. (*Journ. R. Soc. Arts*, June 25, 1920.)—A colloidal solution, or sol, of clay can be clarified by immersing in it two electrodes attached to a source of electrical potential. The clay particles then travel to the anode, where they give up their electric charges and form a coagulated mass. The water of the sol is driven to the cathode. The finely divided impurities, such as silica, mica, and pyrites, are either carried away by the flow of water or are collected at the cathode. In the actual machine the clay suspension enters the lower part of a tank and is urged by paddles through a perforated cathode which surrounds the anode. The latter is a metal cylinder revolving slowly at a distance of three-quarters of an inch from the other electrode. Clay collects on the anode, is removed by a scraper and falls down a chute away from the machine. One thousand tons of pure clay per year is produced by a machine with a cylinder five feet long and two feet in diameter. The clay leaves

the machine as a sheet one-fourth to one-half inch thick and contains only 25 per cent. of water. It is possible to treat many varieties of clay by this process.

Among the advantages derived from this method of preparation are these:

a. Saving of fuel, since the finishing of articles made from clay thus obtained can be completed at lower temperatures than with ordinary clays.

b. Articles can be made which show little contraction after burning. This is because the sintering temperature is lowered and the fusing point raised by this method of preparation.

c. Vitrified bricks and roofing can be made from material which otherwise could not be employed for this purpose.

d. Whiter porcelain and earthenware are got from osmosed clay than from ordinary clay. Pyrites and other sources of discoloration have been removed.

Electrical osmosis is applicable also to the tanning of leather, the treatment of metal slimes and the removal of ash from gelatine.

G. F. S.

Spontaneous Evaporation. H. B. WEISER and E. F. PORTER. (*J. Phys. Chemistry*, May, 1920.)—In 1859 Babington published the results of a series of investigations on the rate of evaporation of salt solutions. One of his conclusions was this: " There are some salts which, being dissolved in water, do not retard evaporation, and some salts which, so far from retarding, actually accelerate evaporation." This result seemd so unlikely that it was thought well to repeat the experiments on which it rested. This was done, great care being taken to have uniform conditions of evaporation for water and for the salt solutions, and to avoid the creeping of the latter. The same salts were used as in Babington's work, but in no case did the evaporation of a solution exceed that of water. When the solutions were permitted to creep up the sides of the vessels and thus to increase the area of the surface for evaporation it was observed that water evaporated less rapidly than the solutions. As Babington used saturated solutions the creeping effect was, no doubt, far from negligible in his experiments.

G. F. S.

Foreign Constituents in Unscoured Wools.—*The Weekly News Letter of the United States Department of Agriculture* for June 30, 1920 (vol. vii, No. 48, pages 1-2) reports the amounts of foreign constituents which were found to be present in seventy-three samples of wool, some of domestic, others of foreign origin. Very little potash was present in pulled and washed wools. Lower grade wools apparently contained more potash than the fine grades. Unscoured wools with a low grease content were richer

in potash than those with a high grease content. Even in the
same grade or class of wool, the foreign constituents varied within
wide limits. Thus Ohio delaine, a very greasy wool, contained
from 17.8 to 41.9 per cent. grease, from 2.5 to 4.6 per cent. moisture,
from 14.9 to 38.7 per cent. ash. The extractives (water extract)
soluble in water after removal of the grease, the nitrogen content
of that extract, and its potash (K_2O) were all calculated as per
cent. of the unscoured wool. In Ohio delaine, the water extract
varied between 6.3 and 17.1 per cent., the nitrogen content of the
water extract between 0.3 and 0.8 per cent., and the potash content
between 1.1 and 4.7 per cent. The grease is used in the manufac-
ture of lanolin, and probably may be utilized in leather dressing,
waterproofing, and varnish. Potash and fertilizer may also be ob-
tained as by-products of wool-scouring.

J. S. H.

Formation of Ferrous Sulphide in Eggs During Cooking.—
CHARLES KENNETH TINKLER and MARION CROSSLAND SOAR (*Bio-
chemical Journal*, 1920, xiv, 114–119) find that the greenish-black
coloration on the surface of the yolk of a " hard-boiled " egg ap-
parently is due to the formation of ferrous sulphide. The hydro-
gen sulphide which is necessary for the formation of ferrous sul-
phide is produced by the decomposition of a sulphur compound in
the egg white. The coloration does not occur if the hard-boiled
egg be placed in cold water immediately after cooking, since the
decomposition of the sulphur compound is checked by the cooling.

J. S. H.

Antiscorbutic properties of concentrated fruit juices have been
studied by ARTHUR HARDEN and ROBERT ROBISON (*Biochemical
Journal*, 1920, xiv, 171–177). Orange juice may be reduced to a
dry residue by evaporation under suitable conditions at a low tem-
perature without undergoing an appreciable loss of the antiscor-
butic accessory factor or vitamine. This residue retains a con-
siderable degree of potency after storage for two years in a dry
atmosphere at ordinary temperatures. The preparation of such
dried orange juice on a commercial scale apparently is quite prac-
ticable, and should prove of considerable value where an antiscor-
butic material is required in a highly concentrated and stable form.

J. S. H.

Making Wood Fire Resistant with Paint. (*Technical Notes,
Forest Products Laboratory*, U. S. Forest Service, Madison, Wiscon-
sin, No. 106, 1920.)—Fire retardent paints are the most practical
means so far discovered by the Forest Products Laboratory by which
small amounts of wood can economically be made fire resistant.
The only other known methods of decreasing the inflammability
of wood are to keep it wet, or to inject into it certain chemicals

under pressure. These methods, though more effective than painting, are usually either impracticable or too expensive to be considered.

Ordinary calcimine, or whitewash, has proved in tests to be as fire resistant as any paint covering tried. It is cheap and convenient to use. Although it will not prevent the burning of wood exposed continuously to a high heat, a good coat of calcimine on wood will decrease the danger of a blaze spreading from burning cigarettes, sparks, matches, and similar small sources of fire. Calcimine is, of course, more effective for inside than for outside use.

For exterior use numerous patented fire retardent paints are available. An effective outdoor paint which has been developed at the Forest Products Laboratory consists of linseed oil, zinc borate, and chrome green. This paint has maintained its fire resisting properties through more than three years of exposure to the weather.

Transportation by Air between Paris and London. (*Le Genie Civile,* June 26, 1920.)—Beginning with August 25, 1919, two companies, one French and the other British, inaugurated daily trips from one capital to the other by airplane. Since the date mentioned two additional French companies and one other English concern have established similar services. The distance is about 400 km., and the trip takes from two to three hours in general. The best time is a little less than two hours. The early afternoon is the time of the flight. From 500 to 700 francs are charged for a trip and excess baggage costs about 9 franc per kg.

From August 25, 1919, to June 2, 1920, in all 1074 single trips were made, 1041 sacks of mail were carried with 1641 passengers and 38,860 kg. of merchandise. This means of crossing the English Channel is growing in favor, five times as many passengers having been carried in May, 1920, as in November, 1919. In this service airplanes with two or four places are the rule, though some have large cabins with room for as many as a dozen people.

G. F. S.

The Meeting of the French Society for Gas Technology. (*Le Genie Civile,* June, 1920.)—A prevalent note was the need of economy in view of the serious fuel shortage in France. M. Rolland d'Estape discussed the use of lignite for the manufacture of gas. He finds it possible to use this low-grade fuel in modern ovens, but regards it as a very poor substitute for coal, since it lowers the output of the plant and introduces elements of danger due to its coming from the coking process in the form of a powder.

The same speaker reported that in Marseilles the gas pressure was reduced from 60 mm. to 25 mm. and even to 10 mm., but the consumption came down only 10 per cent., as the consumers managed to burn almost as much gas in spite of the small pressure.

A different report came from Paris where the lowering of pressure resulted in a distinct lessening of consumption. Such experiments in economy indicate the straits to which the French are driven as the joint result of the destruction of their coal mines by the German invaders, and of the failure of Germany to deliver coal as she promised to do in the Treaty of Versailles.

G. F. S.

Chemical Composition of Cottonseed Oil.—GEORGE S. JAMIE-SON and WALTER F. BAUGHMAN (*Journal of the American Chemical Society*, 1920, xlii, 1197–1204) have analyzed cold-pressed, refined oil obtained from Sea Island cottonseed. The oil had the following composition: Glycerides of myristic acid, 0.3 per cent.; palmitic acid, 20.0 per cent.; stearic acid, 2.0 per cent.; arachidic acid, 0.6 per cent.; oleic acid, 35.2 per cent.; linolic acid, 41.7 per cent.; total, 99.8 per cent. Linolenic acid was not present in the oil.

J. S. H.

Gas Masks in Pulp and Paper Mills. (*Technical Notes, Forest Products Laboratory*, U. S. Forest Service, Madison, Wisconsin, No. 102, 1920.)—Gas masks of a nose-breathing type, with canisters containing special chemicals, are used in the digester house of the Forest Products Laboratory to give protection against sulphur dioxide. These masks enable the operator to make repairs under conditions otherwise unbearable and soon pay for themselves in time saved. Masks of this type are reported by the Bureau of Mines to hold up against 5 per cent. concentration of sulphur dioxide for about fifteen minutes. When it is realized that five parts of sulphur dioxide to one million parts of air can readily be detected, and that at a concentration of one hundred and fifty parts of sulphur dioxide to one million parts of air the air becomes unbreathable, some idea can be gained of the life of a canister even under adverse mill conditions.

In addition to their use in the sulphite mill these masks are of great assistance in the bleach room, where they are worn continuously during the mixing of the bleach liquor. Aside from monetary considerations, the increased comfort and safety of the workmen is sufficient argument in favor of the addition of gas masks to the regular mill equipment.

Lake Tahoe. (*U. S. Geological Survey, Press Bulletin, No. 451*, July, 1920.)—Lake Tahoe, in California, is often said to occupy an old volcanic crater. This is not a fact. It is true that the region about the lake shows evidence of volcanic activity of various kinds and that the water has at times probably been dammed by outpourings of lava, but the lake itself lies in a structural depression—a dropped block of the earth's crust.

The prehistoric Lake Tahoe was larger and deeper than the

present lake, according to the United States Geological Survey, Department of the Interior. During the Neocene epoch and the earlier part of the Pleistocene epoch its water stood much higher than now, but in its overflow it has since cut through the lava dams that maintained it at that height. Distinct beaches that mark the former higher levels of the lake stand about 100 feet above its present surface, but the water doubtless once stood at even greater heights. At Tahoe City the most distinct of these old beaches is a terrace that stands 35 to 40 feet above the level of the lake. It is on this ancient beach that Tahoe Tavern is built.

Artificial Graphite. (*U. S. Geological Survey, Press Bulletin, No. 451,* July, 1920.)—Graphite is manufactured by the Acheson Graphite Company at Niagara Falls, N. Y. This company utilizes the electric power generated at the Falls to manufacture graphite from anthracite coal or from petroleum coke. This product is used mainly in lubricants, but it is also used in paints, foundry facing, preventives of boiler scale, and fillers for batteries.

Artificial graphite may be used for any purpose for which natural graphite is employed, according to the United States Geological Survey, except in the manufacture of large crucibles. Patents have been issued recently, however, for methods of manufacturing crucibles in which artificial graphite may be used. Artificial graphite is peculiarly adapted to the manufacture of certain graphite products, among them graphite electrodes, which are not made from natural graphite and for which the demand has greatly increased in recent years. The table below, published by permission of the Acheson Graphite Company, represents only the manufactured graphite that comes into competition with natural graphite.

GRAPHITE MANUFACTURED BY THE ACHESON GRAPHITE COMPANY, 1915–1919.

	Pounds.
1915	5,084,000
1916	8,397,281
1917	10,474,649
1918	9,182,272
1919	8,163,177

A Directional Hot-wire Anemometer of High Sensitivity, Especially Applicable to the Investigation of Low Rates of Flow of Gases. J. S. G. THOMAS. (*Proc. Physical Soc. of London,* April 15, 1920.)—Two pieces of platinum wire, 1 mm. in diameter, were stretched across the diameter of a tube. They were parallel to each other with an interval of 1 mm. between them. They were perpendicular to the axis of the tube and the plane containing them was parallel to the direction of flow of the gas. The wires formed the two arms of a Wheatstone bridge. They were traversed by a current which raised the temperature to about 300° C.

The bridge was balanced with the air in the tube at rest. The current of air was then started. The two wires had their resistances changed to different extents by the moving air and hence the bridge balance was upset. The galvanometer deflected. It was found that the direction of this deflection was reversed upon reversal of the flow of air. This arrangement may, therefore, be used to find the direction of flow. Moreover, the amount of the deflection was found to be proportional to the velocity of flow up to 4 cm. per second. This instrument was developed in the physical laboratory of the South Metropolitan Gas Co., London.

G. F. S.

Propagation of Light in a Gravitational Field. A. O. RANKINE and L. SILBERSTEIN. (*Phil. Mag.,* May, 1920.)—Is the speed of light near the earth dependent upon the direction of the light oscillations? An experimental answer to this question was found. The speeds of two light waves in which the directions of vibration are at right angles to each other came out almost exactly the same. The difference was so small that were the two kinds of light to start from the same point and travel outwards for a second one would outdistance the other by only three hundredths of a millimetre in the long stretch of 300,000 kilometres.

G. F. S.

The Relation Between the Refractivity and Density of Carbon Dioxide. P. PHILLIPS. (*Proceedings of the Royal Society,* A 684, May 1, 1920.)—The L. Lorenz and H. A. Lorentz formula connecting refractivity and density is $\frac{n^2 - 1}{n^2 + 2} \cdot \frac{1}{d} =$ constant, where n is refractivity and d is density. This fits well in most cases, but shows divergencies when large changes of density are investigated.

Doctor Phillips studied the refractivity of carbon dioxide at 34° C.; that is, above its critical temperature. The range of densities was in the ratio of 1 to 7. He found the above expression not to be a constant, but to vary in such a way that its reciprocal is a linear function of the square of the density.

G. F. S.

The Pressure Distribution on the Head of a Shell Moving at High Velocities. L. BAIRSTOW, R. H. FOWLER, and D. R. HARTREE. (*Proceedings of the Royal Society,* A 684, May 1, 1920.)— The problem proposed to themselves by the investigators was one of great difficulty. Any kind of registering pressure-gauge placed within the shell would need to be insensible to a spin of 11,660 r.p.m. and to the shock of landing. This difficulty was avoided by employing a service time-fuse as a manometer. The rate of burning of such a fuse depends on the total external pressure on the vents. In the fuse a train of gunpowder is ignited by a detonator

pellet by the shock when the gun is discharged. The time of burning is taken as the interval from the discharge of the gun to the explosion of the shell.

In the experiments shells were fitted with caps enclosing the fuses. In each cap was a series of holes equidistant from the nose of the shell. The relation between rate of burning and pressure was obtained from a set of experiments made with a fuse body mounted on the shaft of a Laval turbine and run in an air-tight box in which the pressure could be varied.

A series of shells provided with caps pierced with holes was fired along the same trajectory at brief intervals and the time of burning of the fuses was noted. From this and the length of the fuse the rate of burning was deduced and in turn from the rate of burning the pressure was derived at the part of the shell where the holes were located. This last step was made by reference to the laboratory experiments under varied pressure. " At all speeds in the range covered the pressure has a maximum positive value at the nose of the shell. The pressure falls rapidly as the point of observation moves toward the base, and is negative some distance before the cylindrical part of the shell is reached."

G. F. S.

Fine Spun Asbestos. (*U. S. Geological Survey Press Bulletin No. 448*, June, 1920.)—The earliest use of asbestos was for spinning and weaving, to make incombustible thread and yarn rope and cloth, and this has continued to be the most important use of asbestos ever since the days of the Greeks and Romans. Only the best grades can be used for this purpose, according to J. S. Diller, of the United States Geological Survey. Thread can now be spun so fine that it will run about 32,000 feet to the pound.

Centenary of the Industrial Calculating Machine. (*La Nature*, May 15, 1920.)—The Alsatian financier, Thomas, in 1820 brought out the first model of his calculating machine. To celebrate the centennial of this event an exposition of all types of calculating apparatus was held in Paris in June, 1920.

Four great names in the history of calculating machines are claimed for France: Blaise Pascal, Thomas of Colmar, Maurel and Jayet, and Léon Bollée.

G. F. S.

On the Viscosities and Compressibilities of Liquids at High Pressures. J. H. HYDE. (*Proceedings of the Royal Society*, A 684, May 1, 1920.)—In the transmission of power by worm gears pressures come into play between the lubricated surfaces of the order of five tons per square inch. This investigation was designed to obtain information concerning the viscosity of various oils under such conditions. For all oils it was found that the viscosity in-

creases with the pressure. This increase is especially rapid for mineral oils (F. F. F. Cylinder, Victory Red, Bayonne, Mobiloil " A," Mobiloil " BB ") above the pressure of five tons per square inch. At high pressures the viscosity is as much as twenty times as great as at atmospheric pressure. For animal and vegetable oils (sperm, " trotter," castor, and rape) the increase in viscosity is not so great. At a pressure of seven tons per square inch these have only from four to five times as great a viscosity as at normal pressure. Furthermore, there is a much greater difference between the oils of the mineral class than between those of the other class.

In all cases the compressibility diminishes with increasing pressure and the value of this quantity is not greatly different from the value for water.

Application of Chroncphotography to the Study of the Flow of Water Over a Dam. P. MORIN. (*Comptes Rendus*, May 17, 1920.)—A silvered glass sphere, partly immersed in water, floated along with the current. Sunlight fell upon it and thus a bright source of light was provided. This was photographed along with a scale. The light was shut off at regular intervals by a wheel rotating in front of the camera. The path of the image of the sun was a broken line and the time taken to traverse any portion was known from the rate of rotation of the wheel. The accuracy of the velocity measurement is about $\frac{1}{2}$ per cent.

G. F. S.

Utilization of Tidal Energy. (*Nature*, June 3, 1920.)—The rise in the price of fuel has helped to direct attention both in Great Britain and in France to a study of the methods for getting energy from the rise and fall of water with the tides. The great height of the tides in southwestern England and in western France gives to these countries unusually favorable conditions for such projects of development, since the power which can be obtained from a given area is proportional to the square of the tidal range and since further the cost per horsepower of the necessary machinery diminishes as the working head becomes greater.

The problem is complicated by the occurrence of spring and neap tides. At St. Malo the tidal range of the former is 42.5 feet and of the latter 18 feet. The energy output there is 5.5 times as great at spring as at neap tide.

Various systems of storage have been considered. Compressed air and accumulators seem too costly. A feasible suggestion is to use surplus power to pump into a reservoir at a higher level from which it may flow when need arises. It would, of course, be more economical to employ the power as it is developed.

" Assuming a mean tidal of only 20 feet at springs, and 10 feet at neaps, and adopting the single-basin method of development

with operation on both rising and falling tides, each square mile of basin area would be capable, without storage, of giving an average daily output of approximately 110,000 horsepower-hours. In such an estuary as the Severn, where an area of 20 square miles could readily be utilized with a spring tidal range of 42 feet, the average daily output, without storage would be approximately 10,000,000 horsepower-hours."

It may be well to keep in mind the high tides in the Bay of Fundy.

G. F. S.

Calcium Carbonate in Pharmacy and Medicine.—ADLEY B. NICHOLS enumerates the various forms of calcium carbonate which have been included in the materia medica. Precipitated chalk is precipitated calcium carbonate. Prepared chalk is native chalk purified by elutriation; it is less gritty and more adhesive than the precipitated compound. Calcarea carbonica and corallium rubrum of the homœopathic pharmacopœia are forms of calcium carbonate prepared from oyster shells and the skeleton of the red coral, respectively. Other substances which have served as sources of calcium carbonate are: Crab's eyes, crab's claws, and cuttlefish bone. (*American Journal of Pharmacy,* 1920, xcii, 391–393.)

J. S. H.

Heavy Metals in Foods.—In a study on the Pharmacology of Heavy Metals, WILLIAM SALANT (*Journal of Industrial Hygiene,* 1920, ii, 72–78) states that heavy metals apparently are well borne by the body for a considerable time when taken with food; nevertheless, serious results may follow such ingestion. Hence caution should be exercised in permitting the preparation and sale of foods which contain even small quantities of these metals.

J. S. H.

Self-imposed Inspection of the National Canners' Association is described by H. M. LOOMIS, National Director of Inspection of the Association in the *American Journal of the Public Health,* 1920, x, 521–525. The canners on their own initiative have instituted inspection to improve, standardize, and certify their products. The inspection service and its personnel are under the control of the executive officers of the National Canners' Association, and is supported by an assessment levied on the subscribing canners. Minimum standards of quality have been adopted for canned sardines, corn, tomatoes, string beans, lima beans, peas, pumpkin, sauerkraut, spinach, and fruits. Beginning with the pack of the present year, whenever a standard grade has been adopted by the U. S. Department of Agriculture, the minimum standard for certification by the Association shall not be lower than such

standard grade. Problems relating to the industry are handled by the research laboratory of the Association at Washington and by smaller field laboratories such as have already been established in Maine and in California. At present the inspection certificate is attached to each case of approved canned goods. The placing of a certificate or emblem on each can of food approved by the inspection service is contemplated.

J. S. H.

Cockle-bur Oil.—LELAND B. RHODES (*Journal of the American Chemical Society*, 1920, xlii, 1507–1508) has prepared and analyzed this oil. The burs of the cockle-bur or clot-bur, *Xanthium echinatum*, yield 30.69 per cent. by weight of kernels. The kernels contain 29.89 per cent. oil. The cold-pressed oil, obtained from the kernels, is a drying oil with an iodine number of 140.8 and a saponification number of 190.2. In a test, cockle-bur oil in a film completely dried in five days; pure linseed oil under like conditions required four days to reach the same degree of dryness. The press cake was toxic; guinea pigs, which ate a small amount, died in one day.

J. S. H.

Detection of Formic Acid.—E. COMANDUCCI (*Rend. Acc. Sci. Fis. e Mat. d. Nap.*, 1918, 3a, vol. xxiv, 14) has found that formic acid heated gently with a saturated solution of sodium acid sulphite produces a reddish-yellow liquid, which is characteristic. The test is applicable to formates and in presence of formaldehyde, glycerol, methyl alcohol, and acetic acid. When the liquid to be tested is of the color that the reaction will produce, the following modification has been found to be satisfactory, as it dispenses with the older procedure which was to render the solution acid with sulphuric acid and distil in a current of carbon dioxide.

The modified procedure is to add the solution of sodium acid sulphite and heat carefully to incipient ebullition, cool and add a solution of sodium nitroprusside. The test can be conveniently applied by overlaying the suspected solution with the other, when the presence of formic acid is shown by the production of a green or blue line at the point of contact. A blue precipitate may also be formed later.

H. L.

Uniform Composition of Commercial Stearic Acids and Its Explanation.—BEN H. NICOLET (*Journal of Industrial and Engineering Chemistry*, 1920, xii, 677–679) determined the titer of six samples of commercial stearic acid from five entirely different sources. The titers were surprisingly uniform; and the agreement became startling when they were corrected for the small and varying iodine numbers of the samples, for the maximum

variation in the corrected titers was less than 0.5° C. These titers revealed a remarkable constancy in the ratio of the palmitic acid and the stearic acid to each other in the technical stearic acid; this constancy in ratio was probably due to solid solutions formed between the two acids.

<div align="right">J. S. H.</div>

Experimental Distillation of Kelp at Low Temperatures.— G. C. SPENCER (*Journal of Industrial and Engineering Chemistry,* 1920, xii, 682–684) has made sixteen distillations of dried kelp in an oil-jacketed wood retort at temperatures not exceeding 320° C. Aqueous liquor, tar, and a non-inflammable gas were obtained. The residual charcoal was not sufficiently heated for the good extraction of potash or for use as a filtering medium, therefore kelp must be distilled at a much higher temperature.

<div align="right">J. S. H.</div>

Signal Corps, U. S. A.—In studying the provisions of the Act of Congress approved June 4, 1920, reorganizing the Army, it is found that there will be vacancies remaining in the grade of second lieutenant in the Signal Corps, United States Army, after the officers who served in the World War have been examined and commissioned.

The Signal Corps is charged with the general duty of providing communicational signal service for the Army by means of ordinary telegraphy and telephony, submarine cable, radio telephony, and other instrumentalities.

Signal troops not only operate these instrumentalities, but the Corps is charged with the duty of the research and development of the apparatus employed. For many years the Signal Corps has been one of the Staff Departments of the Army, but on account of the growing importance of the duties of Signal Corps troops, the Congress of the United States, in the reorganization of the Army, made the Signal Corps one of the arms of the line of the Army. The importance of its work in both peace and war in the Army is very great. Speaking of the work done by the Signal Corps in the World War, General Pershing, in an official communication, said:

" The work of the Signal Corps in France stands out as one of the masterful accomplishments of the American Expeditionary Forces."

On account of the wide range of duties, varying from service with troops in the field to research, engineering and development of special apparatus for use of the Army, including that required for meteorology; ultra-violet, infra-red and black light signalling; telegraph and telephone engineering, including simplex, multiplex, and phantom circuits; radio telephony and telegraphy, vacuum tubes, etc., the Signal Corps presents a field which should be attractive to young college men who have the educa-

tional foundation on which to develop along the lines of Signal Corps activities in the Signal Corps technical schools of instruction. In addition to the Signal Corps schools, selected officers are sent each year to Yale University and the Massachusetts Institute of Technology for special courses, the expense of tuition being paid from Signal Corps funds appropriated by Congress for that purpose.

TYPES OF ARTILLERY EQUIPMENT USED BY THE AMERICAN EXPEDITIONARY FORCES IN FRANCE WITH A BRIEF DISCUSSION OF THEIR USES AND THE REASONS FOR THEIR ADOPTION.*

BY

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1. In a paper necessarily as brief as this, it is possible to do little more than touch upon the principal fundamental reasons leading to the adoption of certain types of artillery for the American Army, and to mention in the briefest possible way examples of the various types.

2. The artillery necessary for the proper equipment of a large field force may be divided into four (4) principal classes:

The First Class consists of the Divisional Artillery which is assigned as an organic part of the Division. These guns are never separated from the Division whatever its mission, except in the direst emergency. In all armies this artillery consists of guns of about 3-inches calibre and howitzers of from 4-inches to 6-inches in calibre. I will in a few moments, explain some of the reasons leading to the diversity of opinion in regard to the calibre of the howitzers.

The Second Class consists of Corps Artillery. This artillery includes a gun of 4.7-inches to 5-inches in calibre and a howitzer about 6-inches in calibre.

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* Presented at a meeting of the Mechanical Engineering Section held Thursday evening, February 26, 1920.

The Third Class is known as Army Artillery and includes a gun of about 6-inches calibre and a howitzer of from 8-inches to 10-inches calibre.

The Fourth Class consists of the Army Reserve Artillery which includes all of the special purpose weapons such as the mountain gun of about 3-inches calibre, the antiaircraft artillery, the very heavy howitzers up to 16-inches in calibre, and the railway artillery for maximum ranges. In addition to this

FIG. 1.

View of the famous French 75-mm. "Soixante Quinze" in firing position.

special purpose artillery, the Army Reserve Artillery will include for the purpose of reinforcing weak spots in any given line a certain number of guns of the three first types, namely, Divisional, Corps and Army Artillery.

3. Having in mind these four major tactical assignments of artillery we are able to examine the steps taken by the United States to fill the requirements for each class.

4. At our entrance into the War, the United States had available an utterly inconsequential number of field guns; about 750 all-told, ranging from 3-inches to 6-inches in calibre. Our

guns and ammunition were, of course, of distinctively American design and would not interchange with the material used by any of our Allies.

5. The French and British armies were each using artillery equipment of their own design and on our entrance into the War it appeared utterly undesirable to introduce a third series of designs into the general supply service for the three armies. After consideration of this fact, our General Staff decided, in the summer of 1917, that the American Army so far as the

FIG. 2.
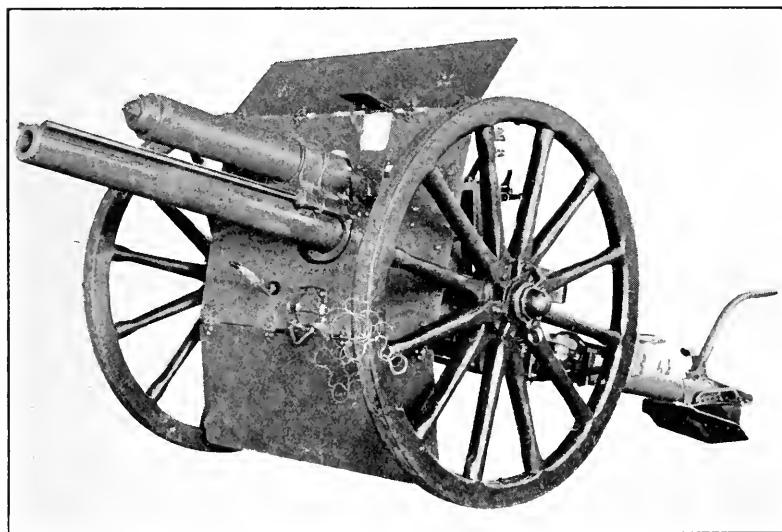
75-mm. gun carriage of the British type. A number of these were manufactured by the Bethlehem Steel Company for both the British and American armies and gave excellent service in the war.

source of its artillery supply was concerned would coöperate with the French, and that our artillery should be as nearly like the French as possible. It was further decided that our artillery ammunition should be completely interchangeable with the French.

6. Following this general policy, by far the greater number of our guns are of French type. We have a few of the British types which were procured for the purpose of utilizing available manufacturing capacity in Great Britain. In general, and for the purpose of facilitating supply, our American types were abandoned.

7. To take up in detail the Divisional Artillery—the 75 mm. gun is the principal Divisional weapon. It is the gun which

FIG. 3.
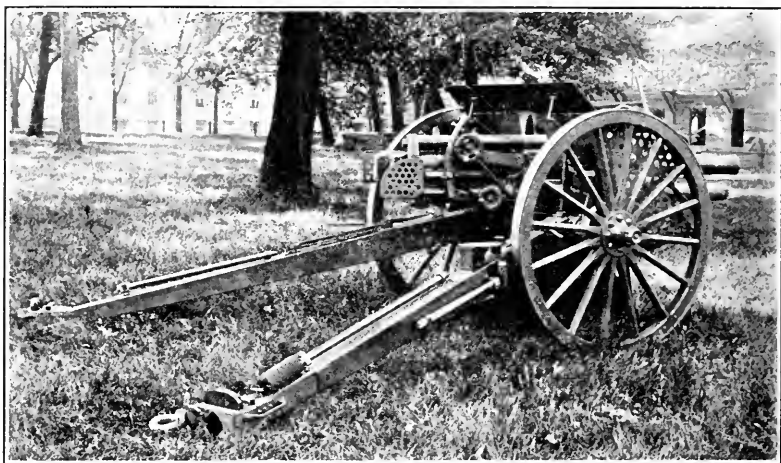
View of the American 75-mm. split trail carriage. A pioneer of this type.

FIG. 4.
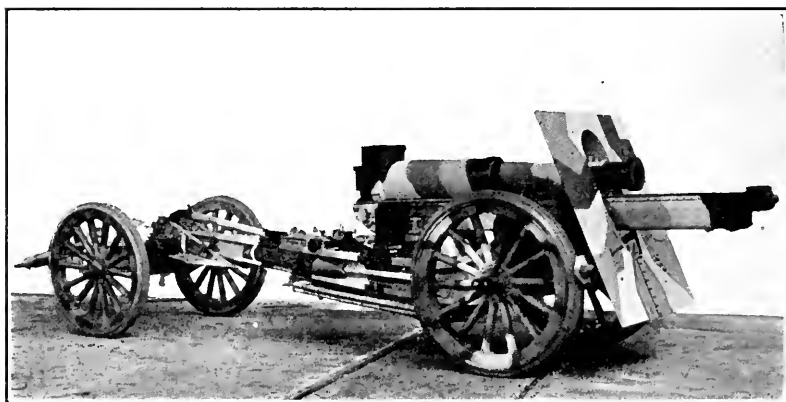
155-mm. Howitzer carriage and limber. This howitzer was very largely used by the American and French armies. About 700 complete units have been completed in the United States. This howitzer was one of the most useful weapons of the war and is credited with having fired the last shot from the American lines against the enemy.

stands closest to the Infantry and is the one whose sole purpose is the destruction of personnel. There are more 75 mm. guns

in an army than all other calibres combined. It is, therefore, the calibre of which we have heard and always will hear the most. We find guns of 75 mm., 3-inch, 77mm. and 3.3-inches in all of the armies. In other words, every country having any experience in war has come to the conclusion that the proper divisional gun is that about 3-inches in calibre and firing a projectile of about 14 to 15 pounds in weight. Some of the reasons for this universal decision are:

First: A gun and carriage of about this calibre, firing a pro-

FIG. 5.
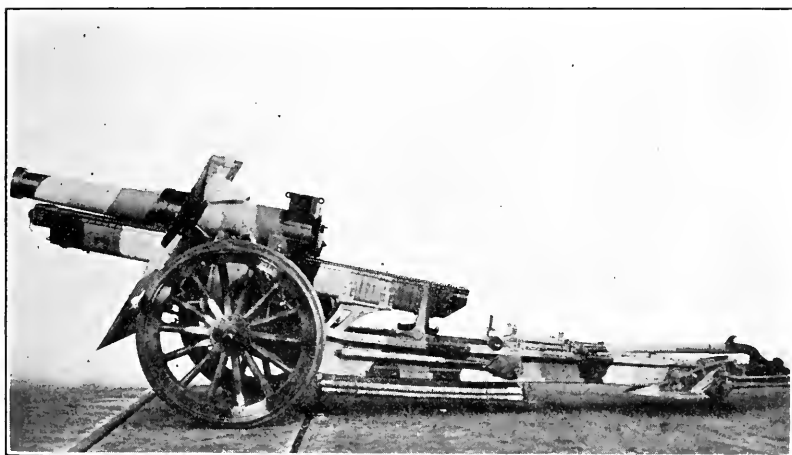
View of the 155-mm. howitzer carriage of the Schneider type.

jectile of about this weight can be readily handled by about six horses.

Second: Projectiles of about this weight are the heaviest that can be handled by one man with any rapidity.

Third: A projectile of this weight is about the smallest that contains a satisfactory bursting charge, and its man-killing characteristics are but little less than are those of projectiles of considerably greater weight.

Fourth: While extremely long range is generally desirable in all guns, it has been found by experience that the Divisional Artillery need fire but few rounds at ranges greater than nine to ten thousand yards. This the 75 mm. gun will do.

8. All of these four reasons which operate to about the same extent in all countries have caused the adoption of this 3-inch calibre gun and this 15-pound shell as the main artillery reliance of the Division.

9. The Divisional gun supplied to the American Expeditionary Forces consisted almost entirely of the 75 mm. French field gun. There were under construction and there would have been issued to troops had the war continued, modifications of the

FIG. 6.
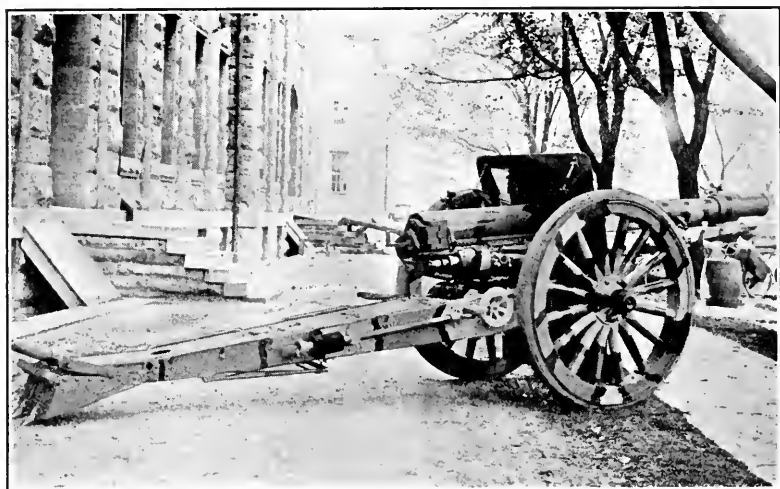
4.7″ gun model of 1906. This is an American model of pre-war design and was in use by American troops prior to the Armistice. It is one of the pioneer carriages of the long recoil type.

British and American types of field guns and carriages which would fire the same 75 mm. ammunition.

10. You will have noted that in the four principal general types of artillery there will be found for the Division, for the Corps, and for the Army one calibre of gun and one calibre of howitzer. The historical and textbook description of the difference between a gun and a howitzer states that a gun is a weapon designed to fire at angles of elevation up to about 15 to 20 degrees and that the howitzer is a similar weapon designed to fire at angles of elevation greater than 20 degrees and up to 40 to 60 degrees. As matters stand to-day, however, our new guns

and carriages are all designed to fire at angles of elevation up
to and including 65 degrees.   A howitzer of a given weight
varies from a gun of the same weight and mobility in that it is
designed to fire a projectile of about twice the weight at a lower
muzzle velocity and at a shorter maximum range.   In other
words, as the mobility or weight is the governing element in
the design of Divisional Artillery we find that for the same
weight as the 75 mm. field gun, we can get a howitzer which

FIG. 7.
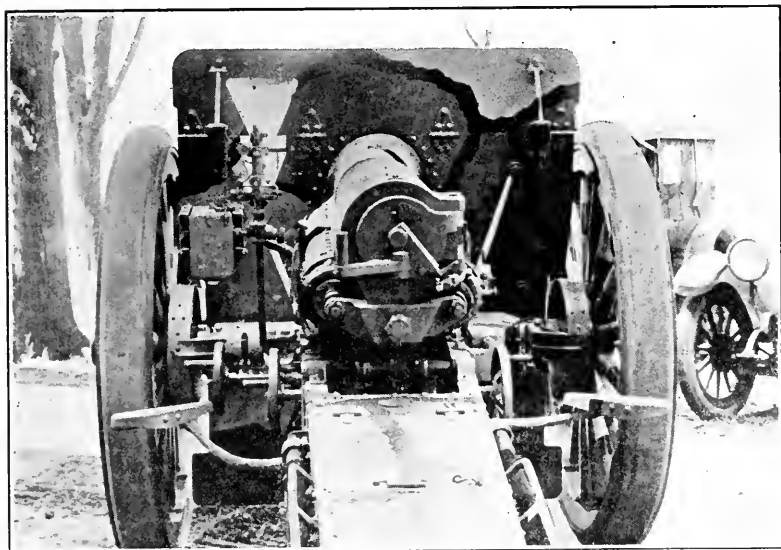
Rear view of the 4.7″ gun model of 1906, showing elevating, traversing and sight mechanisms.

will fire a projectile weighing about twice as much, but we find
also that we can get only about 75 to 80 per cent. of the range.
The fact, however, that the shells from the howitzer will fall
at an angle closer to the vertical than the shells from the guns
make the howitzer of great value in searching trenches and there-
by reaching the enemy in places where the gun shells would do
little damage.

11. Theoretical consideration of the above facts leads us to
the adoption of a howitzer of slightly over 4-inches in calibre,
firing a projectile of about 30 pounds, as a companion Divisional

FIG. 8.

View in firing position of the 155-mm. "Filloux" gun, which was one of the most useful and efficient pieces of artillery employed in the War by both the French and American armies. It fires a 95-pound projectile over 18,000 yards. Note the wide traverse and high elevation at which gun can be fired.

FIG. 9.
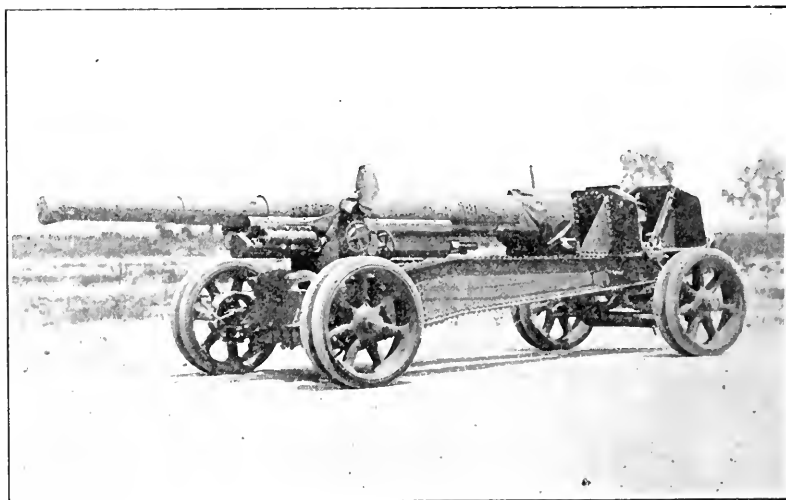
155-mm. "Filloux" gun in the travelling position.

piece to the 75 mm. gun. As a matter of fact, however, our Divisional Artillery was supplied with howitzers of 155 mm. (6-inches) calibre which fired projectiles weighing 90 pounds. The reason for this was that the French Army was already so equipped. The British Army had for this purpose 4.5-inch howitzers and the German, Austrian and Italian Armies had 105 mm. (slightly over 4-inches). There were two schools of thought on this sub-

FIG. 10.
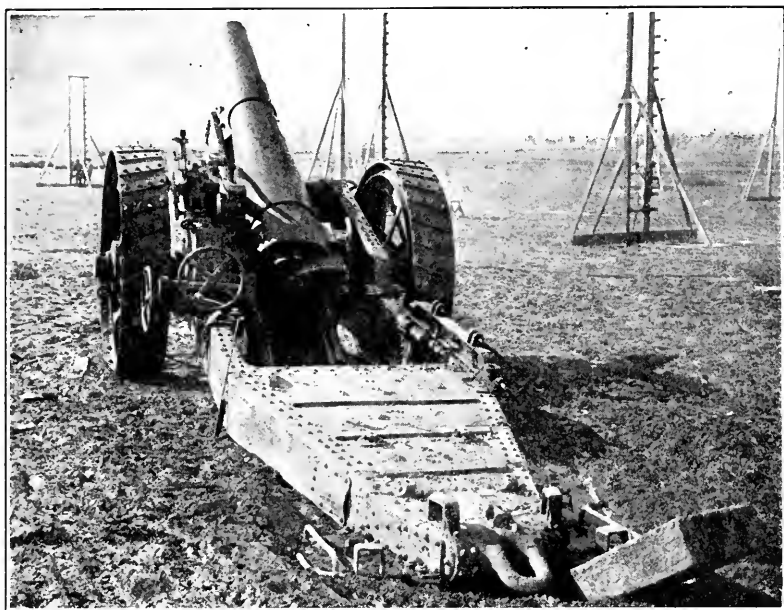
The 8″ field howitzer carriage of British design. These howitzers were employed by the British and American armies. Its range is about 11,000 meters. The projectile weighs 290 pounds.

ject in the French Army. One favoring the very light or 105 mm. howitzer and the other favoring the heavier or 155 mm. calibre; but for reasons of production it was finally decided that howitzers of one calibre only could be manufactured in France and despite the much greater weight, and, therefore, loss of mobility the 155 mm. was issued to Divisions. As our Army was to coöperate both in the matter of tactics and supply with the French Army it was thought best to adopt the same calibre. The French Army was being supplied with the Schneider 155 mm.

howitzer of modern design and we decided to issue the same weapon to our troops.

12. The Divisional Artillery of the American Expeditionary Forces was, therefore, equipped with 75 mm. field guns and with 155 mm. howitzers.

13. *The Second* principal tactical class is the Corps Artillery. A corps, as you know, consists of two or more divisions together

Fig. 11.
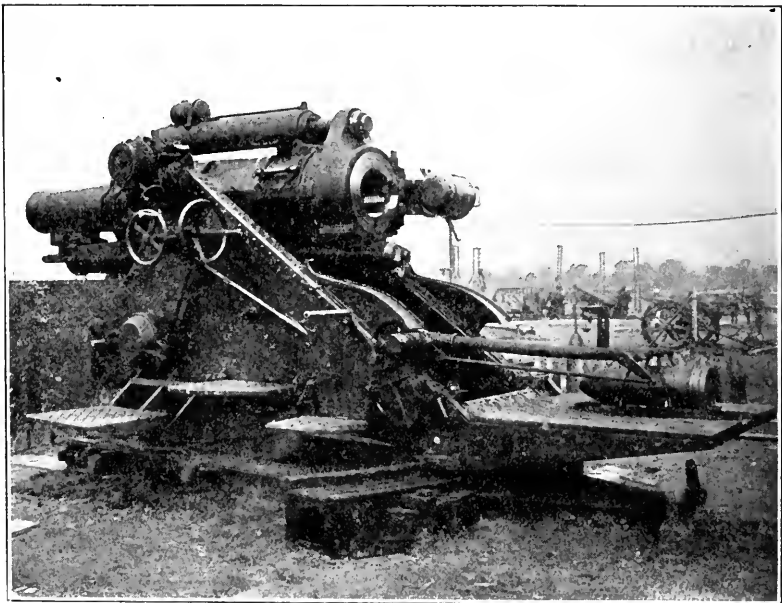
The 9.2 inch howitzer in the loading position.

with a special artillery unit known as the Corps Artillery. As I have stated before the Divisional Artillery has for its principal mission the killing of men. The mission of the corps artillery is not principally the killing of men, but is the destruction of the Divisional Artillery of the opposing army.

14. In order to accomplish its purpose of destroying the enemy Divisional Artillery, it is of course obvious that the Corps Artillery must have greater hitting power, which means shells of greater weight; and it must also have greater range in order that

its men may not themselves be destroyed by the very artillery which it is seeking to annihilate. In addition to these requirements of greater weight of ammunition and greater range the Corps Artillery is required to have a considerable amount of mobility. It need not be moved so readily as the Divisional Artillery, but it must with practically no strengthening of roads, culverts or pontoon bridges be able to be moved anywhere. It must have some ability to go across country.

FIG. 12.
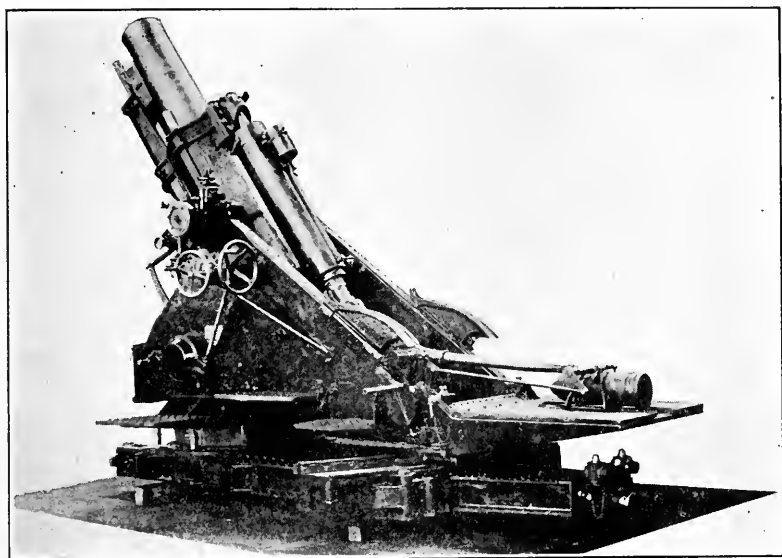
British 9.2″ howitzer.

15. All of these considerations led to the adoption of a 4.7-inch calibre for the gun of our Corps Artillery. A careful examination of the situation as to this calibre showed that the 4.7-inch gun of our own standard design was up to the requirements for this purpose and was better suited to the needs of our situation than the British or the French weapons of about the same character. This gun fires a shell weighing 45 pounds.

16. For the Corps howitzer, it is universally considered that the 155 mm. (6-inch) calibre is ideal. It has the same mobility as the 4.7-inch gun and fires a 90-pound shell.

FIG. 13.
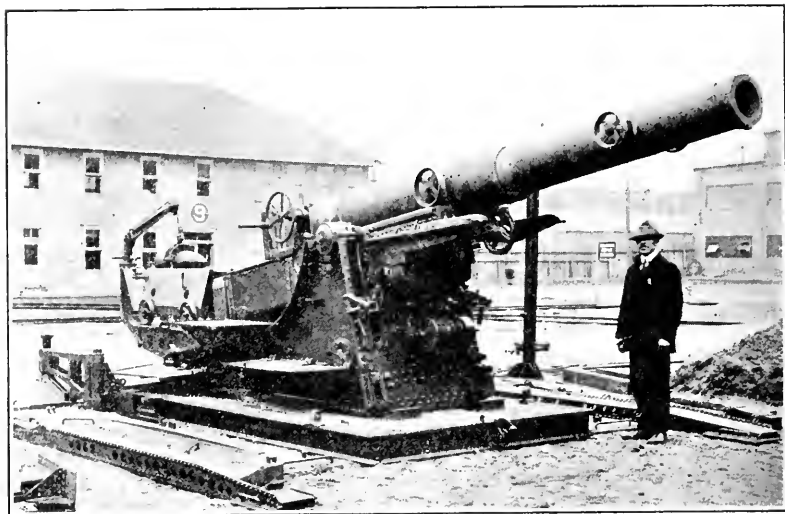
  ¯ View of the 240-mm. howitzer and carriage in firing position.   This howitzer fires a 356-
pound projectile with a range of 17,000 yards.   It is the most powerful type of field artillery
transported on wheels which was built for the American army.

FIG. 14.
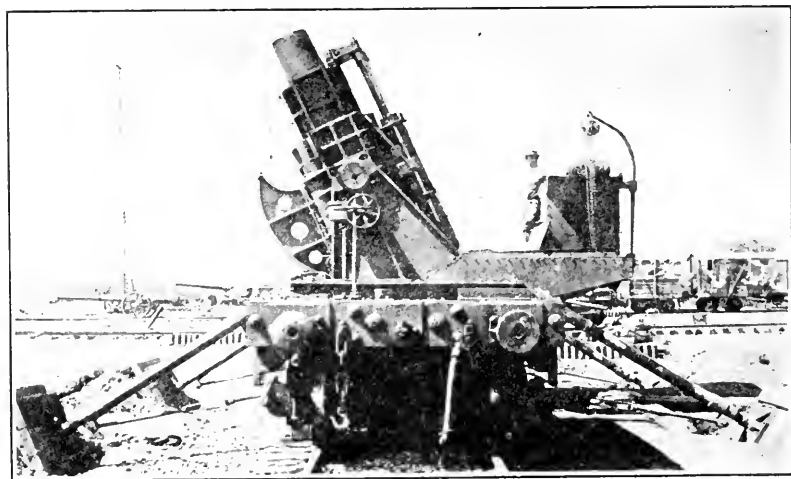
12″ mortar railway mount, model of 1918.   Range 15,000 yards with 700-pound projectile.
Capable of being fired at any angle to the track.

17. As I have stated before, under ideal conditions a lighter howitzer is desirable for use in the Division, but because of limitations in our production program we adopted the view point of the French and issued 155 mm. howitzers to our Divisions and to our Corps. I desire to emphasize particularly the fact that the 155 mm. howitzer is distinctively a Corps weapon and is not one which should normally be issued to Divisions as part of their standard equipment. This is in accord-

FIG. 15.
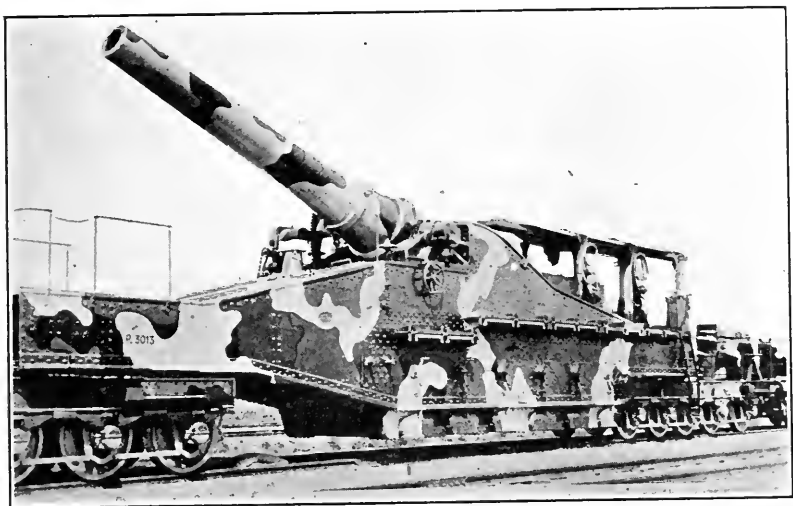
320-mm. howitzer on French sliding railway mount. A large number of these units were in the hands of the American troops in France.

ance with the best Artillery and Ordnance opinion in all countries and was advisedly deviated from in our case, not for tactical reasons but for production reasons.

18. In accordance with the decisions which I have heretofore referred to, some of our Corps were equipped with American 4.7-inch guns, but in most cases our Corps Artillery guns were of the 155 mm. calibre, a gun recognized as being too heavy for normal Corps assignment, but one which had to be used in this case for reasons of production expediency. This gun fires a shell interchangeable with that of the 155 mm. howitzer.

19. *The Third* great sub-division is the Army Artillery. A

field army normally consists of about five corps and it has assigned
to it artillery units of greater power and longer range than the
Corps Artillery.   These guns and howitzers are for the purpose
of destroying the enemy Corps Artillery and of interdicting traffic
upon roads leading up to the enemy position over which his
supplies must come.   They should have a normal range for the
gun of from 18,000 to 25,000 yards and of the howitzers about
16,000 to 18,000 yards.

FIG. 16.
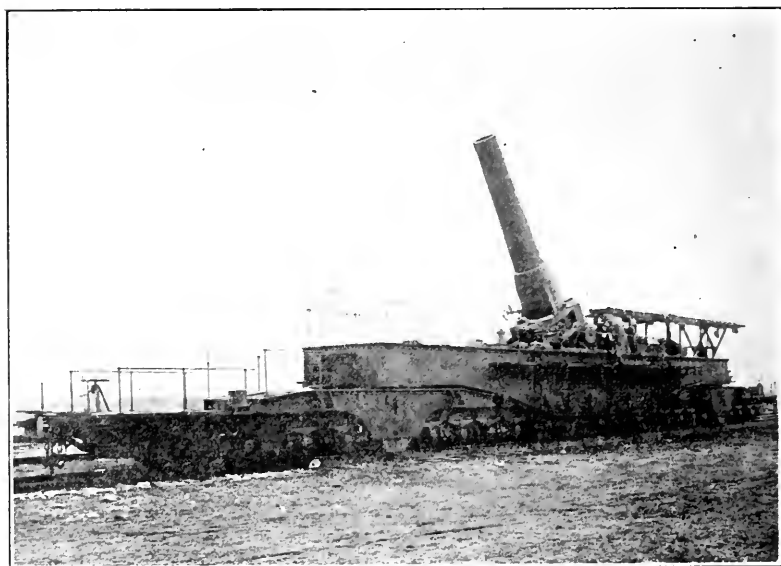
French 520-mm. howitzer on railway mount.   This howitzer throws a 3,000 pound projectile
about 20,000 yards.

20. During the War, the French had developed a 155 mm.
gun known as the Filloux.   This gun had the required range
and was considered by all to be ideal for the purpose.   It was,
therefore, adopted for our Army.   We considered the British
8-inch howitzer to be the most available companion piece for
the 155 mm. Filloux gun.   We were able to secure a supply of
these howitzers in England, and we therefore, adopted this
calibre so that for our Army Artillery we had a 155 mm. French
gun firing a 90-pound projectile and an 8-inch British howitzer
firing a 200-pound projectile.   They were both admirably adapted

to their purpose except that the 8-inch howitzer was of somewhat short maximum range, about 11,000 yards.

21. *For the Fourth* tactical class, namely, the Army Reserve Artillery, the situation was somewhat confused. This Artillery should primarily be of great range and great hitting power. It is for the purpose of destroying bothersome enemy batteries which cannot be reached by corps or army artillery. It is also used for the purpose of bombarding enemy rest camps, supply depots, railroad yards, ammunition dumps and for long range interdiction.

22. The projectiles must be of great destructive power, cap-

FIG. 17.
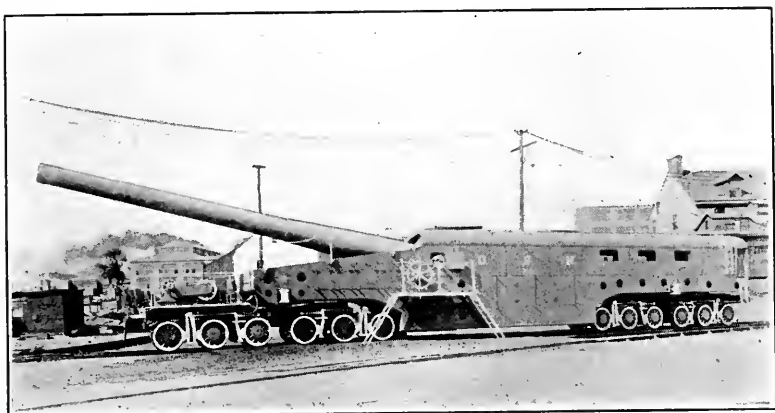
14″ Navy railway mount. Range with 1200-pound projectile 45,000 yards.

able of destroying the most massive field works, concrete dugouts and both semi-permanent and permanent fortifications. These actually used varied in weight from 200 to 3,000 pounds with explosive charges of from 50 to 500 pounds.

23. The French used for this purpose a 280 mm. howitzer firing a 600-pound projectile and a number of seacoast or Naval guns of calibres varying from 7-inches to 20-inches. These latter were mounted on Railway Carriages.

24. The British used howitzers of 9.2-inches in calibre and a collection of naval and seacoast guns up to 14-inches in calibre. The Germans, Austrians and Italians did about the same thing.

25. In considering the needs of our Army for Artillery of

this class, we had before us, first the French 280 mm. howitzer, which had too short a range, about 11,000 yards; second, the British 9.2-inch howitzer which had even shorter range than the French 280 mm.; and third, our own design of 9.5-inch howitzer which was then practically complete and which had a very satisfactory range. In view of the fact that the French had certain guns of 240 mm. calibre and a supply of ammunition

FIG. 18.
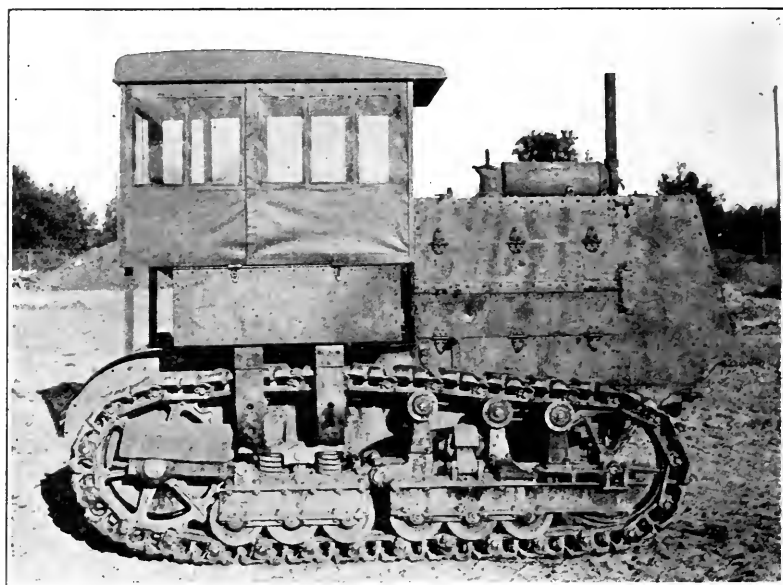
10-ton artillery tractor. Weight 21,500 pounds. Maximum speed 6 miles per hour. Draw bar pull low speed 8,000 pounds.

for them, we decided to change our 9.5-inch calibre to 240 mm. (9.45-inches) and to manufacture this type. In the meantime, we decided to procure from the British a number of 9.2-inch howitzers to fill the gap until our own guns could be delivered. As a matter of fact, due to the length of time required for the production of this class of material, only the 9.2-inch howitzers were used by our Army.

26. In addition to the above we withdrew from our Fortifications a number of 8-inch, 10-inch and 12-inch guns and mortars to be placed on railway mounts for the extreme long range firing

referred to before. The French were able to supply the requirements of our Army for this type of artillery until our own could be received.

FIG. 19.
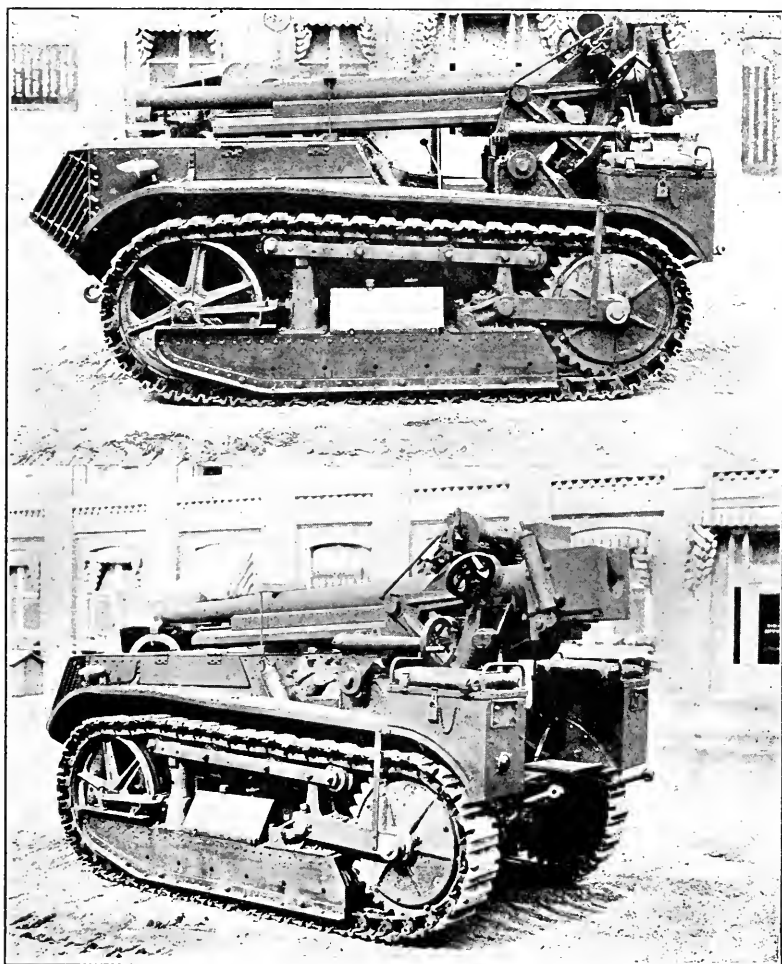
75-mm. gun on caterpillar mount. Capable of travelling at speeds of about 12 miles per hour. Maximum range 9,000 yards. Total weight 10,600 pounds.

27. Our Navy had a number of 14-inch guns which they were able to spare from their ship construction program and five of these guns were mounted by the Navy upon railway mounts

and were used for long range interdiction firing at various points
of the front.

28. It will be of interest to note here that all nations engaged
in the present war were compelled to make up their supply of
this fourth and vitally important class of artillery almost entirely
from guns in existence at the beginning of the War.   There was
neither time nor manufacturing facilities available for the manu-
facture of new and modern big guns.   Consideration of these

FIG. 20.
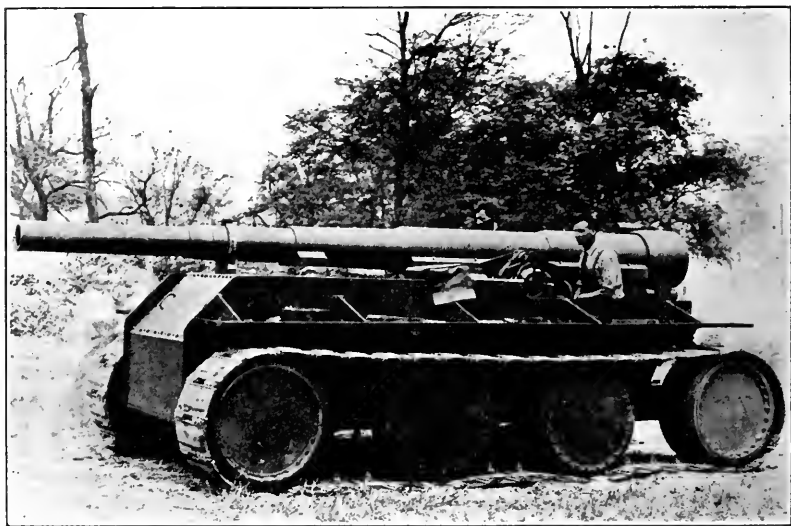
155-mm. gun on Christie wheel caterpillar mount.   This mount can travel as a wheeled
vehicle or as a track laying caterpillar.   Maximum speed as wheel vehicle 15 miles per hour.
Maximum speed as caterpillar vehicle 10 miles per hour.   Total weight 44,000 pounds.

facts makes it evident that it behooves any nation to plan and
prepare far into the future on this class of artillery.

29. I have described the types of artillery assigned normally
to the principal tactical organizations.   It must not be under-
stood, however, that this assignment is unvarying, as such is not
the case.   In actual practice, the Divisional weapons form an
integral part of the Division and are never separated from the
Division.   The Corps Artillery and the Army Artillery are
more elastic and are often drawn from their normal assignments
to fulfil special missions.   The Army Reserve Artillery is

obviously special purpose artillery and is assigned to whatever Corps or armies are in special need of their services, depending upon the objectives to be obtained.

30. In speaking of types of artillery one must not forget that the object of artillery fire is to land a properly operating projectile on the target, and, therefore, we must remember that in all artillery design we must start with the projectile and work

FIG. 21.
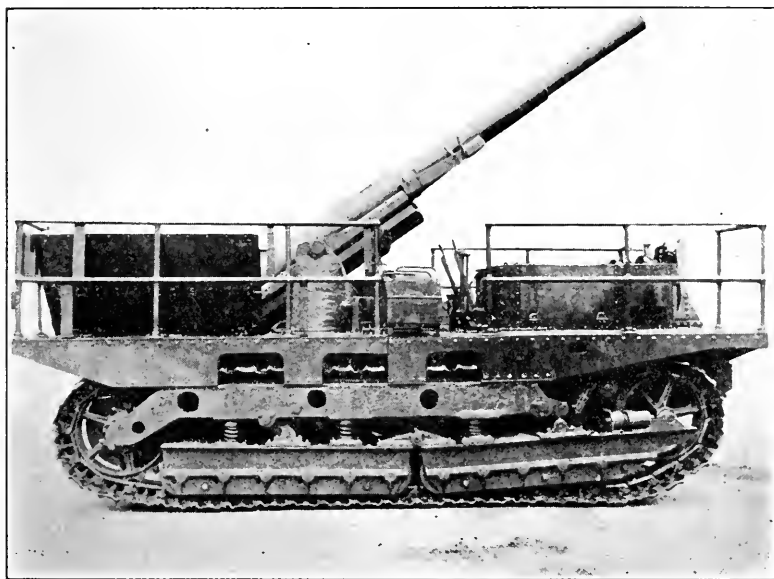
155-mm. or 6″ gun on caterpillar mount. Total weight including all equipment 61,000 pounds. Range with 96-pound projectile, 17,000 yards. Maximum road speed 5 miles per hour.

back to the gun and carriage. Any gun or any carriage is good if it will enable you to place projectiles upon the target. Guns and carriages are, therefore, a means to an end and the projectile is the prime factor in the equation. The projectile is of simple appearance on the outside and excites ordinarily but little curiosity as compared to the mechanism of the breech of a gun, or the recoil system of a carriage. The design and production of ammunition is however, of even greater importance than the design and production of guns and carriages.

31. For each standard type of gun such as the 155 mm., we

have about 16 different kinds of projectiles and I regret that my time is too short to enter into a discussion of some of the details on this phase of the subject.

32. Up to the present War we had considered that all Artillery except some special railway types must be transported by means of horses. The experience of previous wars had indicated that Divisional Artillery must be drawn by not more than six horses;

FIG. 22.
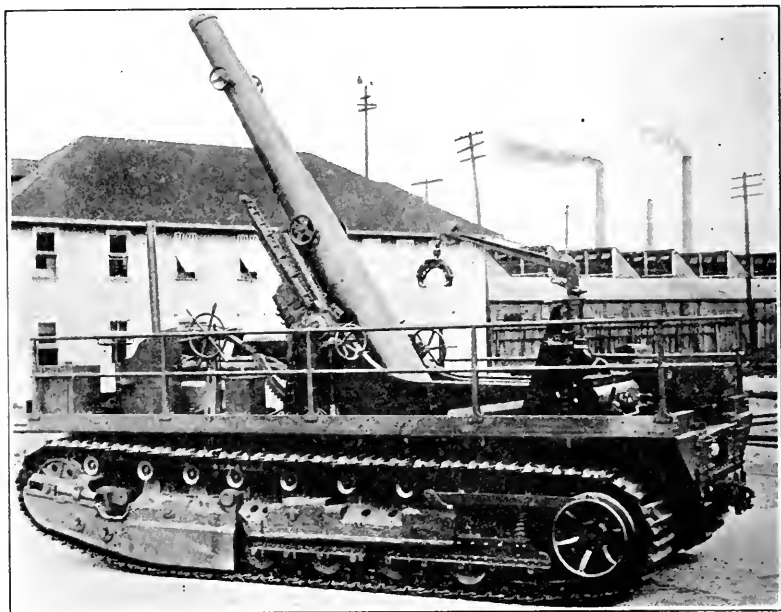
240-mm. howitzer on caterpillar mount.   Maximum road speed 4 miles per hour.   Total weight 109,000 pounds.

that Corps Artillery must be of a weight which could be drawn by eight horses and that heavy artillery must be divided up into a number of small loads each of which could be drawn by about eight horses.

33. Wheeled automobile traction is, of course, suitable on good roads, but is helpless on poor roads and across country. In 1912 and 1913 all of the major countries, with the United States in the lead, were experimenting with machines commonly known as caterpillar tractors for the purpose of hauling their

heavy artillery. The French and British purchased a large number of these machines in this country after their entrance into the War.

34. The French in spite of its limitations used a number of wheeled trucks for hauling their artillery and the British, Germans, Austrians and Italians did the same. The Divisional Artillery was, however, invariably drawn by horses. This was largely due to the fact that horses could be obtained and to the fact that tractors could not be obtained in sufficient quantities and in any case were not of entirely suitable design.

35. We were considerably in advance of other countries in our studies of this subject and we contemplated using horses for our Divisional Artillery with caterpillar tractors for all of the remainder, except our railway artillery. As a matter of fact, before the end of the war, it was decided to motorize one-half of all Divisional Artillery, due to the shortage of horses and the almost impossibility of securing forage for them.

36. We find then that at the time of the Armistice the United States was using horses for its Divisional Artillery, one-half of which were to be replaced as soon as possible with caterpillar tractors. All of our other Artillery was being motorized as rapidly as conditions permitted.

37. Three of the outstanding lessons of the War are; first, the tremendous use of ammunition, second, the development of special ammunition such as the gas shell, and third, the great increase in mobility and striking power which is given artillery by the advent of heavy railway artillery, motor traction and especially the caterpillar tractor.

38. The last is probably the greatest of all. The size of cannon and the supply of ammunition will cease to depend upon the muscle of the horses and will to a greater extent than ever before be independent of the roads. The offensive power of the artillery has been enormously increased and with the advent of tractors, tanks and self-propelled gun mounts able to negotiate streams five feet or more deep, it is not far fetched to imagine an army equipped with hundreds of armored machines moving freely over the country like ships at sea and engaging in almost hand-to-hand combat.

Permanent Preparation of the Antiscorbutic Vitamine.—The antiscorbutic food accessory or vitamine protects the body against scurvy. This disease attacks individuals who are on a restricted diet which does not contain such foods as *fresh* vegetables, fruits, milk, and meat. The antiscorbutic vitamine is abundant in the juice of fresh lemons. P. W. BASSETT-SMITH (*Lancet*, 1920, cxcviii, 1102–1105) has devised the following process for obtaining a preparation in which the vitamine retains its efficiency for a considerable period of time. Juice of fresh lemons is filtered through muslin, then is passed through filter paper under reduced pressure. The filtrate is evaporated *in vacuo* over sulphuric acid at a temperature of 13.5° to 15.5° C. The residue is a non-crystallizable syrup, which is worked into as stiff a paste as possible by incorporation with a dry mixture of anhydrous lactose 97 parts and gum tragacanth 3 parts. The paste is divided into portions, each of which contains the juice of one-half lemon and is equivalent to 24 c.c. of the juice—the dose for an adult. Each portion is rolled, faced with the dry mixture of lactose and gum, and pressed into a lozenge. Five days are required for the entire process of manufacture. The lozenges readily dissolve in water containing a small amount of sodium bicarbonate. They have been kept for three or more months at temperatures of 15°, 30° and 37° C. without loss of antiscorbutic power, and did not become mouldy. The temperature of 37° C. was least satisfactory; the lozenges became darker and softer; the lactose caramellized, and the vitamine was slightly affected. The antiscorbutic value of these lozenges was demonstrated by experiments on guinea-pigs which are extremely susceptible to scurvy.

J. S. H.

Ammonia-free Water.—According to GERALD C. BAKER (*Journal of Industrial and Engineering Chemistry*, 1920, xii, 798–799), ammonia-free water, which is required in the determination of ammonia, is readily prepared by permitting distilled water to flow slowly through a filter of "permutit," a synthetic hydrated silicate of sodium, and aluminium. Using distilled water containing 0.7 part of ammonia per million, 100 gallons of ammonia-free water were prepared with a filter containing 3 gallons of permutit. It was then necessary to regenerate the filter by treatment over night with 2 gallons of a 10 per cent. solution of common salt, followed by washing. While the water obtained by this mode of purification was ammonia-free, its mineral content was increased, and its nitrate, and albuminoid nitrogen were not removed. The raw water available was rather hard, and was not rendered ammonia-free by passing it through the permutit filter at as slow a rate as possible.

J. S. H.

THE USE OF ALTERNATING CURRENTS FOR SUB-MARINE CABLE TRANSMISSION.*

BY

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ABSTRACT.

THIS paper contains the results of experiments performed by members of the Signal Corps Research Laboratory, Bureau of Standards, in an attempt to develop a method or methods of signal transmission over submarine cables which would permit of a more effective use of existing cable systems.

In the method proposed and developed, signals are transmitted by means of alternating currents simultaneously with the normal battery or direct-current operation of the cable. Currents of several different frequencies may be used, reserving a given frequency for each message, and by tuning or equivalent methods at the receiving end these messages may be separated, so that the simultaneous transmission of a number of messages is rendered possible.

Accurate determination of the fundamental physical properties of a particular cable for different frequencies has been accomplished, and the results are given herewith. From these physical properties accurate calculations for any length of cable can be made, so that the design of proper apparatus becomes purely a laboratory problem.

Actual trial of the proposed alternating-current method was made covering distances up to approximately 700 kilometres, with results which were in all cases completely satisfactory, indicating that the method is an entirely feasible one, and one which will render cables of this length, and undoubtedly of several times this length, much more useful.

I. THE GENERAL PROBLEM.

In March, 1919, in response to a request by the Chief Signal Officer for a consideration of the possibility of improving cable communication methods, the Signal Corps Research Laboratory

* Communicated by Maj. Gen. George Owen Squier, Chief Signal Officer, U. S. A.

commenced work with a view to ascertaining whether any practicable scheme could be devised which lay within its power to develop. After some deliberation it was decided that a possibility existed of using alternating currents as a means for transmitting signals over a submarine cable. The plan was not to use very low frequencies (5 to 10 cycles per second) and the ordinary type of receiver galvanometer, or equivalent apparatus, such as constitute the Squier Alternating Current Method ("On an Unbroken Alternating Current for Cable Telegraphy," George O. Squier, Proceedings of the Physical Society of London, August 15, 1915), but to use a frequency sufficiently high to produce an audible tone which could be received by means of an ordinary telephone receiver and further, so that several such alternating currents of different frequencies could be sent over the cable at the same time and separated at the receiving end by any one of the several well-known methods of tuning. Success in such a proposed scheme would make possible the multiplexing of submarine cables and, of course, provide for transmitting many more messages in a given time than can be done with present methods. Whatever success might be attained would be a net gain to the art, because the regular operation of the cable with direct current would proceed uninterruptedly.

As has long been known, the attenuation of alternating currents in or along submarine cables is very great on account of the resistance and capacity. This fact was considered at the time of formulating ideas in regard to possible methods, and calculations were made to determine the approximate magnitude of the attenuation for typical lengths and constructions of cables. The results of all calculations indicated that it would only be through the medium of powerful amplification at the receiving end that any success could be hoped for in the use of alternating currents of a frequency sufficiently high to permit of tuning, and over cables of such length as to make the method of military and commercial value. Had accurate information been available as to the values of the fundamental electrical properties of a cable when acted upon by an alternating electromotive force, rigorous calculation of the total attenuation could have been made, and upon this as a basis the amplifier design worked out purely as a laboratory problem.

As a matter of fact, little information was available concern-

ing the fundamental properties of a cable subjected to alternating currents of different frequencies. In common with all electrical systems the resistance of a cable should increase with increase in frequency, but the amount of this increase could be determined only by experiment. The magnetic field produced by the current within the cable sets up currents in the surrounding water and steel armor so that, in a general way, the increase in resistance with increase in frequency might well be expected to be similar in type to that observed in the case of a simple coil affected by the immediate proximity of another short-circuited coil. The direct-current, or zero-frequency, value of resistance is accurately known for any cable.

In regard to the self-inductance (coefficient of self-induction) of a cable no information could be found. The immediate presence of the steel armor and the uncertainty as to the geometrical distribution of the return current are factors which would make its calculation quite unreliable, if not worthless. Whatever its value might be, however, its variation with frequency should be of the same type as the variation of the apparent self-inductance of the simple coil system referred to in the preceding paragraph.

Because of the fact that the dielectric portion of the cable is well localized geometrically and of quite definite physical properties (being composed of either rubber or gutta percha) it would normally be expected that the apparent capacity and the dielectric loss coefficient would be dependent upon the frequency in the same way as in the case of a simple condenser, i.e., a slight decrease in capacity and a practically constant power-factor angle.

The above general analysis is amply substantiated by the experimental results obtained from the measurements made on an actual cable. As the Signal Corps has available and operates the cable system between Seattle, Washington, and Sitka, Alaska, as well as a number of short cables in southeastern Alaska, it appeared that the most desirable procedure would be to utilize these various lengths of cable, as already laid, for the investigation of the problem in hand. The most important part of the experimental work lay in the determination of the four fundamental electrical properties previously mentioned, for such results are applicable generally. With such apparatus as could be developed in the short time available, however, excellent results

were obtained in the practical application of this method of signalling.

The description of apparatus used and the results obtained follows:

II. POWER SOURCES.

Whatever form the electrical signaling methods may take, safety to the cable insulation demands that the voltage impressed between cable conductor and sheath be limited to 70 volts. With an alternating emf. of sinusoidal wave form this means a limitation to 50 volts effective value. Throughout the range of

PLATE I.
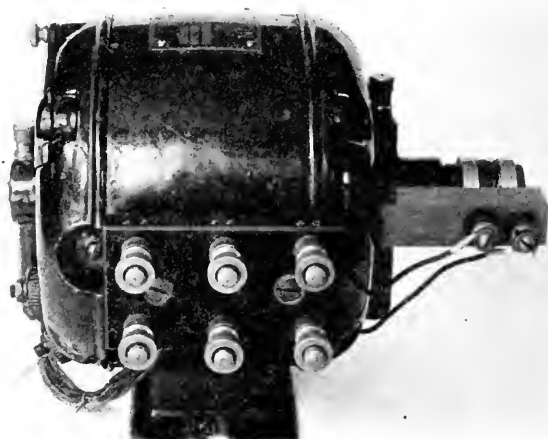
frequencies from 0 to 1400 cycles per second preliminary approximate calculations indicated that a power of not over 40 watts would be required to impress this voltage on the cable. Preliminary calculations also showed that it would not be reasonable to expect much success from the use of frequencies higher than 1400 cycles per second.

For frequencies of from 7 to 40 cycles per second an inverted rotary converter was used as the power source. This machine was made by mounting a pair of slip rings on the shaft of a small direct-current motor and connecting them to electrically opposite points in the armature winding. The converter was driven and the voltage controlled by using the proper number of dry cells. Plate I shows the converter with its slip rings, and Plate II shows

the wave forms of voltage and current obtained when it is connected to a capacity load. The higher harmonics in the current wave I are considerably magnified when the machine feeds thus into a condenser, but since along a cable the higher frequencies are damped or attenuated much faster than the lower, these higher frequencies in the current are of little consequence. As matters turned out, this low-frequency generator was used very little.

For higher frequencies, an oscillating vacuum-tube generator capable of delivering 50 watts at any frequency above 20 cycles per second was developed. In this set standard Signal Corps

PLATE II.
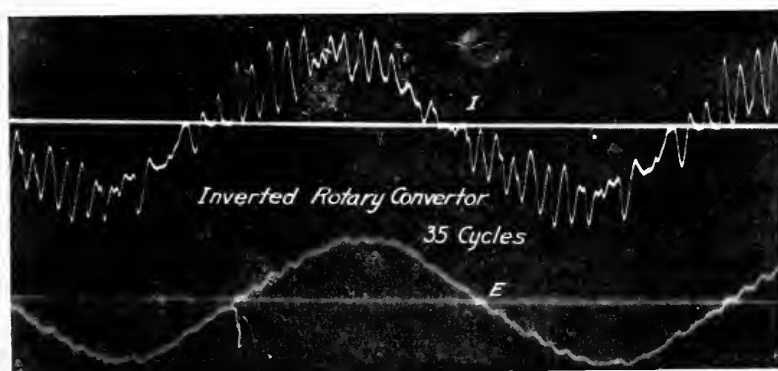
50-watt vacuum tubes were used which, in order to gain flexibility of control, were arranged with one tube in an oscillating circuit and one tube in an amplifier circuit which was actuated by the first tube. From the last, or amplifier, tube the power was withdrawn by means of an iron-cored transformer.

In order to secure constancy in the frequency calibration an air-core inductance coil was used in the oscillating circuit. This coil, wound with No. 18 B. & S. double cotton-covered wire, contained approximately 3500 turns. Its ouside diameter was 28 cm. and its axial length 7.6 cm. Taps were brought out at intervals to provide for flexibility in the adjustment of the circuit conditions. When oscillating vigorously, the high voltage developed across the coil made it necessary to use a mica condenser capable of withstanding a working stress of 1000 volts, effective

alternating. A ten-microfarad condenser, adjustable in steps of 0.01 microfarad, gave excellent control of the frequency. Fig. 1 shows the essential features of the circuit arrangement.

The power output of the set was adjusted by means of the rheostats in the filament battery circuits. Separate storage bat-

Fig. 1.
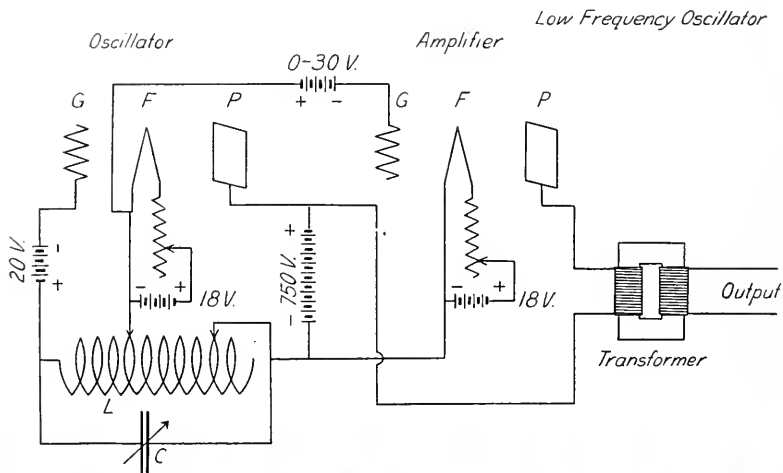
Plate III.
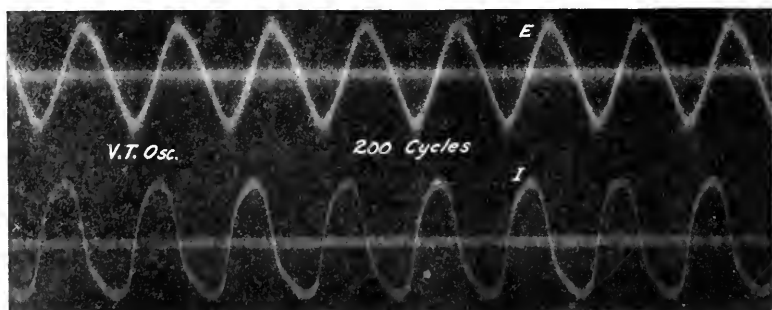
teries were used for lighting the filaments, while a single battery of approximately 600 dry cells was used in the plate circuits of both tubes. For all ordinary purposes it was found possible to calculate the frequency from the known values of capacity and inductance in the oscillating circuit, using the usual formula. This is true for the kind of circuit used when the condenser capacity is large in comparison with the capacity of the coil. The

following tables give the principal electrical properties of the oscillating circuit, and show how a complete range of frequencies can be covered by the use of only two of the taps in the coil:

TABLE I.
Inductance of Oscillator Coil.
Taps Counted from Inside of Coil Outwards.

Taps	Turns	Inductance henrys	
0–1	324	0.0142	Outside diameter, 28 cm.
0–2	648	0.0587	
0–3	972	0.138	Axial length, 7.6 cm.
0–4	1296	0.254	
0–5	1620	0.408	Winding of No. 18 B. & S. gage, double
0–6	1944	0.605	cotton insulated wire.
0–7	2268	0.846	
0–8	2592	1.125	
0–9	2916	1.448	
0–10	3240	1.818	
0–11	3456	2.094	

TABLE II.
Frequency Calibration of Oscillator.
Frequency in Cycles Per Second when Condenser is Connected Across Taps 0–11 and Across Taps 0–3.

Capacity mf.	Taps 0–11 frequency	Taps 0–3 frequency
30.2	20.00	. . . . . .
11.1	33.01	. . . . . .
10.0	34.78	135.5
9.0	36.66	142.8
8.0	38.88	151.5
7.0	41.57	161.9
6.0	44.90	174.9
5.0	49.19	191.6
4.0	54.99	214.2
3.0	63.50	247.4
2.0	77.77	303.0
1.5	89.80	349.8
1.0	109.9	428.4
0.9	115.9	451.6
0.8	122.0	479.0
0.7	131.5	512.1
0.6	142.0	553.1
0.5	155.5	605.9
0.4	174.0	677.4
0.3	200.8	782.2
0.2	245.9	958.0
0.1	347.8	1355.0

Plate III shows the wave forms of current and voltage pro-
duced by the oscillator when operating at a frequency of 200
cycles per second and when feeding into a capacity load.

Plate IV shows the arrangement of the panel containing the
various elements of the oscillator. The coil and condenser are
included in the photograph. The oscillator here described was
used for the major portion of all experimental work. In certain

PLATE IV.
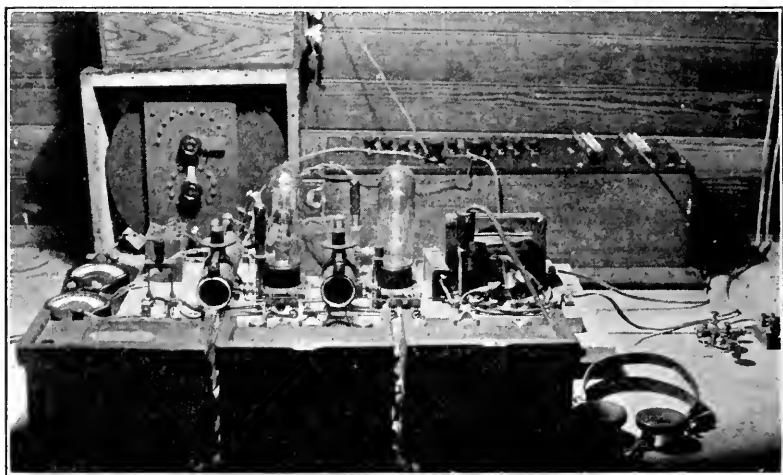
cases, where only a small amount of power was required, as in
the calibration of apparatus, a similar but lower-powered oscil-
lator was used.

MEASUREMENT OF THE ELECTRICAL PROPERTIES OF THE SEATTLE-SITKA CABLE.

Upon arrival at Seattle, Washington, in June, 1919, steps
were taken to proceed immediately with determination of the
fundamental electrical properties of the cable and of their de-
pendence upon the frequency. Several methods are available for
making such determinations, but the one selected as being most
suitable for the case in hand was that in which the apparent
impedances of a moderate length of cable are measured by means
of an impedance bridge, both when the remote end is short cir-
cuited and when it is open circuited.

A short length (14 kilometres) of cable of the same type as the main Seattle-Sitka cable was available continuously for this experimental work. It extended from the foot of University Street, Seattle, to the cable hut at Fort Lawton, and at both ends the cable passed directly into salt water, making conditions practically uniform and ideal throughout its length. Excellent ground connections at both ends were provided by soldering leads to the several strands of the cable sheath. The conclusion that the physical arrangements, were such as to eliminate errors arising from end effects was amply borne out by the results of certain check measurements to be described later.

The technical specifications for the cable upon which the measurements were made are given in Table III. The cable in question is made up of a stranded copper core, rubber insulation bound with tape, a layer of jute, and then the stranded steel armor with its serving of impregnated jute.

TABLE III.

Alaskan Cable Specifications.

Data taken from Signal Corps Manual No. 3, Chap. 11, p. 73.

Type, 1903, Deep sea

Outside diameter of cable	2.06 cm.	
Weight of whole cable in air	881	kg. per km.
Weight of whole cable in water	569	kg. per km.
Weight of armor wire	577	kg. per km.
Weight of jute and compound	217	kg. per km.
Weight of tape	16.1	kg. per km.
Weight of rubber insulation	43.1	kg. per km.
Weight of copper	32.4	kg. per km.
Breaking stress 6610	kg.	
Elastic limit 4990	kg.	
Copper resistance at 15.5° C.	4.59 ohms per km.	
Dielectric resistance at 15.5° C. . . . . .2280 megohms for 1 km.		
Electrostatic capacity	0.266 mf. per km.	

Before doing any experimental work all apparatus was carefully calibrated. Only two separate standards, namely, a capacity standard and a resistance standard, were required to establish the accurate calibration of all condensers, resistances, and inductances used. For the former, the Bureau of Standards certification of section 0.1 A (0.1000 mf.) of Leeds and Northrup mica condenser No. 47839 was accepted. In order to avoid cumulative errors in the fourth significant figure another cipher was added to the above

value in making up the calibration data. For a resistance standard the Leeds and Northrup precision Wheatstone Bridge No. 3445, installed in the Seattle Cable Office, was used. Before accepting this bridge as standard the sections therein were carefully compared and also checked against other high-grade resistance boxes. In the few cases where the indications of electrical meters are quoted, the meters had been calibrated against auxiliary standards calibrated by the Department of Physics of the University of Washington.

FIG. 2.
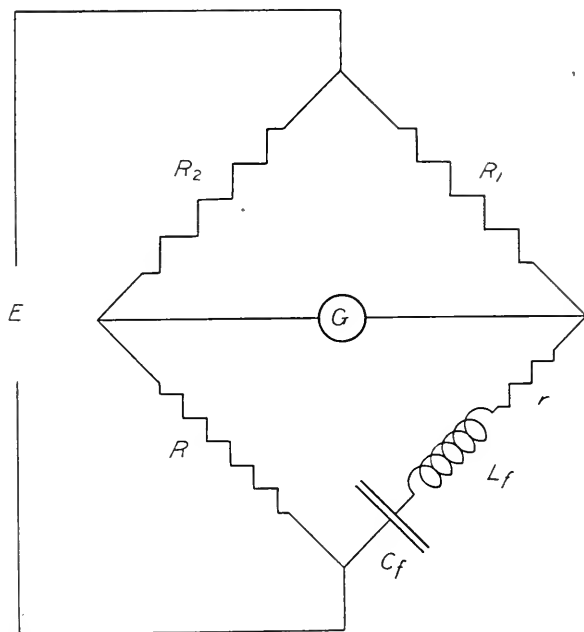
Frequencies were determined in terms of capacity and inductance by means of the resonance frequency bridge shown in Fig. 2. In this bridge, the conditions for balance are

$$
\left.
\begin{aligned}
R_1 R &= R_2 r \\
\omega^2 &= \frac{1}{L_f C_f}
\end{aligned}
\right\}
\tag{1}
$$

in which $\omega = 2\pi f$ and $f =$ frequency in cycles per second. The L_f or C_f adjustment for balance can be made with nicety, so that the frequency determinations are of the same degree of accuracy

as the values taken for the two standards of capacity and resistance. In some of the field work calibrated tuning forks were used to give fixed frequencies to which the oscillator frequencies were adjusted. Elimination of beats between the sound of the fork and the sound produced by the alternating current in a telephone receiver served, in this method, to determine the frequencies to within one cycle per second, or closer.

FIG. 3.

$$L = R_1 R_2 C_0 \qquad r = \frac{R_1 R_2}{R}$$

$$C = \frac{R_1}{R_2} C_0 \qquad g = \frac{R_1}{R_2 R}$$
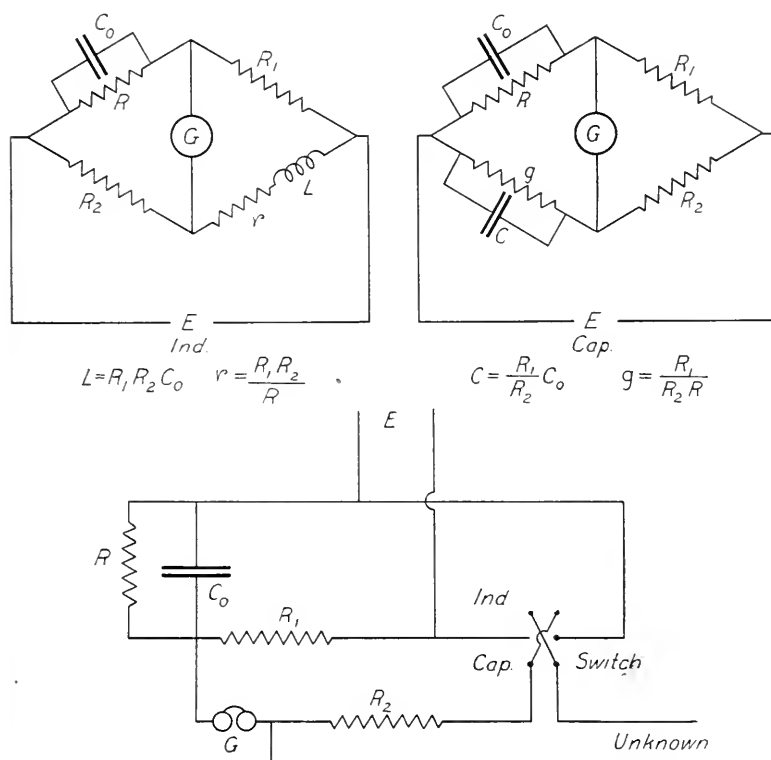
The type of alternating-current impedance bridge used in making the measurements is shown in Fig. 3, and is more fully described in Sections 103 and 104 of Pernot, " Electrical Phenomena in Parallel Conductors," vol. i. For an inductive impedance with the " IND." arrangement of the bridge, the apparent resistance r, and the apparent self-inductance L, are obtained from the formulæ given in the figure. With the " CAP." bridge

arrangement, the apparent conductance g, and the apparent capacity C, are obtained from the appropriate formulæ. Therefore, impedances Z, or admittances Y are given by

$$
\left.\begin{array}{l}
\text{"IND." bridge, } r = \dfrac{R_1 R_2}{R}, \ L = R_1 R_2 C_0. \ Z = r + j\,\omega\,L, \ Y = \dfrac{I}{Z} \\[2ex]
\text{"CAP." bridge, } g = \dfrac{R_1}{R\,R_2}, \ C = \dfrac{R_1}{R_2} C_0, \ Y = g + j\,\omega\,C, \ Z = \dfrac{I}{Y}
\end{array}\right\} \quad (2)
$$

For frequencies above 100 cycles per second a telephone receiver was used as a current detector, while for lower frequencies a vibration galvanometer was employed. Insulating transformers were used in both the power input and galvanometer circuits. All of the elements entering into the bridge were carefully calibrated against the previously mentioned standards, and the results in all cases are given in terms of the corrected values.

The essential features of the mathematical analysis leading to a determination of the fundamental line properties from the two impedance measurements, previously referred to, are given here for convenience in reference. The fundamental properties, whose values at the different frequencies are desired, are:

$$
\left.\begin{array}{l}
r = \text{resistance per unit length} \\
L = \text{self inductance per unit length} \\
g = \text{dielectric-loss coefficient (leakance) per unit length} \\
C = \text{electrostatic capacity per unit length}
\end{array}\right\} \quad (3)
$$

or, as more compactly expressed,

$$
\left.\begin{array}{l}
Z = \text{impedance per unit length} = r + j\,\omega\,L \\
Y = \text{admittance per unit length} = g + j\,\omega\,C
\end{array}\right\} \quad (4)
$$

With the remote end of the line short-circuited, and then with the remote end open-circuited, the respective impedances are (see Pernot, " Electrical Phenomena in Parallel Conductors," vol. i, sections 95 and 100) :

$$
\left.\begin{array}{l}
Z' = U \tanh Vl = \text{apparent short-circuited impedance} \\
Z'' = U \coth Vl = \text{apparent open-circuited impedance}
\end{array}\right\} \quad (5)
$$

in which

$$
\left.\begin{array}{l}
U = \sqrt{\dfrac{Z}{Y}} = \text{infinite-line impedance} \\[2ex]
V = \sqrt{Z\,Y} = \text{propagation constant} \\
 = \text{length of line or cable.}
\end{array}\right\} \quad (6)
$$

The problem is to evaluate Z and Y in terms of Z'' and Z', since the two last impedances are those which are determined by measurement. The auxiliary quantities U and V are also desired.

By multiplication of the two equations in (5)

$$U = \sqrt{Z'\,Z''} \tag{7}$$

Then, from equations (5),

$$V = \frac{1}{l}\,\tanh^{-1}\frac{Z'}{U} = \frac{1}{l}\,\coth^{-1}\frac{Z''}{U} \tag{8}$$

The two quantities U and V, which directly determine the behavior of the system in the transmission of alternating currents of the particular frequency in question, are thus immediately determined. The fundamental electrical properties are derivable from them by the aid of equations (6);

$$\left.\begin{aligned} Z &= r + j\,\omega\,L = UV \\ Y &= g + j\,\omega\,C = \frac{V}{U} \end{aligned}\right\} \tag{9}$$

This completes the solution, for the imaginary portions in equations (9) when divided by ω give respectively the self-inductance L and the capacity C.

In the process of computing, the inverse hyperbolic tangent of the complex quantity $\frac{Z'}{U}$, as required by (8), is most easily obtained by logarithmation after expressing the tangent in exponential form. The result is

$$V = \frac{1}{2l}\,\ln\frac{U - Z'}{U + Z'} \tag{10}$$

In order to obtain a check on the experimental work, similar measurements were made from both ends of the 14-kilometre length available. As a further check, measurements at different frequencies were made of the apparent impedance at one end when the remote end was closed through a known impedance. Having found the fundamental line properties at these same frequencies, the apparent impedance can be calculated in terms of them and the known impedance at the remote end. The formula for this apparent impedance is

$$Z_a = \frac{Z_0\cosh Vl + U\sinh Vl}{\cosh Vl + \dfrac{Z_0}{U}\sinh Vl} \tag{11}$$

where Z_0 is the known impedance at the remote end and Z_a is the apparent impedance.

A comparison of the calculated and observed values of Z_a furnishes a basis for estimating the accuracy of the fundamental determinations.

Tables IV, V, and VI give the corrected values of the quantities observed in the bridge measurements. They lead to values of r and L or of g and C through the formulæ pertaining to the type of bridge used, and the results must, in some cases, be corrected by the conductance of a known resistance shunting the line terminals connected to the bridge. In Table IV the frequencies f were determined directly by adjusting the oscillator frequencies to those of calibrated tuning forks. The other values tabulated are those of the quantities shown in the bridge diagram, Fig. 3. Observations 1, 2, and 3 are not given because they were preliminary, trial settings, not made with much care. In Tables V and VI, L_f and C_f are the corrected values of inductance and

TABLE IV.

Corrected Data from Impedance Measurements Made at Seattle End.

Length of cable, 14.294 km.

No.	Bridge type	Shunt resistance	f cyc./sec.	R_1 ohms.	R_2 ohms.	R ohms.	C_0 farads
		Cable short circuited at remote end.					
4	IND	Inf.	400	99.96	99.92	106.54	0.53558×10^{-6}
5	IND	Inf.	384	99.96	99.92	107.85	0.56993×10^{-6}
6	IND	Inf.	320	99.96	99.92	113.81	0.68624×10^{-6}
7	IND	Inf.	200	99.96	99.92	123.87	0.93999×10^{-6}
8	IND	Inf.	512	99.96	99.92	98.28	0.32313×10^{-6}
9	CAP	Inf.	824	1000.4	999.6	117.33	0.21960×10^{-6}
10	CAP	Inf.	652?	1000.4	99.92	1111.6	0.00000×10^{-6}
		Cable open circuited at remote end.					
11	CAP	200.14	400	1000.4	99.92	1187.0	0.37592×10^{-6}
12	CAP	200.14	200	1000.4	99.92	1700.0	0.38829×10^{-6}
13	CAP	200.14	320	1000.4	99.92	1391.8	0.38143×10^{-6}
14	CAP	200.14	512	1000.4	99.92	923.99	0.36076×10^{-6}
15	CAP	200.14	824	1000.4	99.92	493.44	0.24626×10^{-6}
16	CAP	200.14	640?	1000.4	99.92	664.00	0.32112×10^{-6}
17	CAP	200.14	634?	1000.4	99.92	703.87	0.33055×10^{-6}
18	CAP	200.14	824	1000.4	99.92	492.74	0.24580×10^{-6}
19	CAP	200.14	435	1000.4	99.92	1100.1	0.37224×10^{-6}
20	CAP	200.14	256	1000.4	99.92	1558.9	0.38505×10^{-6}

In observations 10, 16, and 17 the frequencies were determined from the capacity and inductance settings of the oscillator, so that they may be in error by a number of cycles. These observations were not used in the determination of the line properties. Observation 10 was taken particularly in order to observe the change in impedance of the short-circuited cable from an inductive to a condensive nature. At this observation the reactance was zero.

capacity involved in determining the frequency by means of the resonance bridge shown in Fig. 2. In a few cases the frequencies, as determined by direct comparison with tuning forks, are given in place of L_f and C_f.

TABLE V.

Corrected Data from Impedance Measurements Made at Fort Lawton End.

Length of cable, 14.294 km.

No.	Bridge type	Shunt resist.	L_f henrys	C_f farads	R_1 ohms	R_2 ohms	R ohms	C_0 farads
			Cable short circuited at remote end.					
21	IND	Inf.	0.31320	0.50387×10^{-6}		99.96	99.92	104.24	0.49839×10^{-6}
22	IND	Inf.	0.14140	0.50387×10^{-6}		99.96	99.92	91.87	0.09316×10^{-6}
26	IND	Inf.		$f = 199.3$		99.96	99.92	122.98	0.92814×10^{-6}
28	IND	Inf.	0.39895	0.95447×10^{-6}		99.96	99.92	118.21	0.78543×10^{-6}
23	CAP	Inf.	0.42433	0.10000×10^{-6}		99.96	99.92	115.11	0.21731×10^{-6}
24	CAP	Inf.	0.24900	0.10000×10^{-6}		499.90	99.92	588.54	0.10050×10^{-6}
25	CAP	Inf.	0.30151	0.050051×10^{-6}		99.96	99.92	107.04	0.72090×10^{-6}
			Cable open circuited at remote end.					
29	CAP	Inf.	0.39895	0.95447×10^{-6}	1000.4	99.92	7148.2	0.38458×10^{-6}
30a	CAP	500.5		$f = 199.3$	1000.4	99.92	3459.2	0.38733×10^{-6}
30b	CAP	500.5		$f = 199.3$	1000.4	99.92	3471.3	0.38634×10^{-6}
31	CAP	Inf.	0.31320	0.50387×10^{-6}	1000.4	99.92	2975.0	0.37648×10^{-6}
32	CAP	Inf.	0.14140	0.50387×10^{-6}	1000.4	99.92	1270.7	0.34647×10^{-6}
33	CAP	Inf.	0.42433	0.10000×10^{-6}	1000.4	99.92	746.88	0.28499×10^{-6}
34	CAP	Inf.	0.24900	0.10000×10^{-6}	1000.4	99.92	508.00	0.16155×10^{-6}
35a	CAP	Inf.	0.30151	0.050051×10^{-6}	1000.4	99.92	478.14	0.04416×10^{-6}
35b	CAP	Inf.	0.30151	0.050051×10^{-6}	99.96	99.92	47.86	0.44327×10^{-6}

TABLE VI.

Corrected Data from Impedance Measurements Made at Fort Lawton End. Check Test with Known Value of Z_0.

Length of cable, 14.294 km.

Remote End Closed Through 100.01 Ohms Resistance ($=Z_0$).

No.	Bridge type	Shunt resist.	L_f henrys	C_f farads	R_1 ohms	R_2 ohms	R ohms	C_0 farads
36	CAP	Inf.	0.39895	0.95447×10^{-6}	499.90	99.92	777.90	0.36732×10^{-6}
37	CAP	Inf.		$f = 199.3$	499.90	99.92	806.91	0.36931×10^{-6}
38	CAP	Inf.	0.31320	0.50387×10^{-6}	499.90	99.92	691.37	0.35527×10^{-6}
39	CAP	Inf.	0.14140	0.50387×10^{-6}	499.90	99.92	567.48	0.32793×10^{-6}
40	CAP	Inf.	0.42433	0.10000×10^{-6}	499.90	99.92	470.87	0.29272×10^{-6}
41	CAP	Inf.	0.24900	0.10000×10^{-6}	499.90	99.92	379.88	0.23276×10^{-6}
42	CAP	Inf.	0.30151	0.050051×10^{-6}	499.90	99.92	320.52	0.15494×10^{-6}

After reduction by equations (1) and (2) the foregoing data yield the apparent impedance (or admittance) components given in Tables VII and VIII. Only four significant figures are tabulated, although all computations, up to and including the final results, were carried out to five.

TABLE VII.

Components of Apparent Impedances from Measurements at Seattle End.

		Cable short circuited			Cable open circuited	
f	No.	r' ohms	L' henrys	No.	g'' mhos	C'' farads
200	7	80.63	0.009389	12	0.0008929	3.888×10^{-6}
256	..	....	....	20	0.0014259	3.855×10^{-6}
320	6	87.76	0.006854	13	0.002197	3.819×10^{-6}
384	5	92.61	0.005692	..	....	....
400	4	93.75	0.005349	11	0.003438	3.764×10^{-6}
435	..	.....	....	19	0.004104	3.727×10^{-6}
512	8	101.63	0.003228	14	0.005840	3.612×10^{-6}
634	..	.....	....	17	0.009228	3.310×10^{-6}
640	..	.....	....	16	0.010082	3.215×10^{-6}
		g' mhos	C' farads			
652	10	0.009007	0.00000×10^{-6}	....	....	....
824	9	0.008530	0.2198×10^{-6}	15 and 18	0.015308	2.463×10^{-6}

Observations 15 and 18 agree so well that the average of their values is tabulated above. The components r', L' or g', C' and g'', C'', go to make up the impedances Z' and Z'', respectively.

TABLE VIII.

Components of Apparent Impedances from Measurements at Fort Lawton End.

		Cable short circuited			Cable open circuited	
f	No.	r' ohms	L' henrys	No.	g'' mhos	C'' farads
199.3	26	81.22	0.009270	30	0.0008899	3.873×10^{-6}
257.9	28	84.49	0.007845	29	0.0014006	3.850×10^{-6}
400.6	21	95.82	0.004978	31	0.003365	3.769×10^{-6}
596.3	22	108.72	0.0009305	32	0.007879	3.469×10^{-6}
		g' mhos	C' farads			
772.6	23	0.008691	0.2174×10^{-6}	33	0.013405	2.853×10^{-6}
1008.6	24	0.008501	0.5028×10^{-6}	34	0.01971	1.617×10^{-6}
1295.6	25	0.009346	0.7212×10^{-6}	35	0.02092	0.4428×10^{-6}

Observation 30 in the above table is the average of the values obtained from observations 30a and 30b in Table V. Similarly with observation 35.

From the components of Z' and Z'' given in the two foregoing tables, the fundamental line properties per unit of length are to be calculated in accordance with equations (7), (8), (9), and (10). Although these equations appear simple, the fact that the quantities entering therein are complex makes the carrying out of the numerical work rather laborious. A sample computation of the kind required is to be found in Section 106, " Electrical Phenomena in Parallel Conductors."

Table IX gives the final results of the computations based upon the data in Tables VII and VIII. In addition to the four fundamental electrical properties, their combinations into impedances and admittances per unit of length are given also.

TABLE IX.

Fundamental Cable Properties per Kilometre.

f	r ohms/km.	L henrys/km.	$10^6 g$ mhos. km.	$10^6 C$ farads/km.	Z ohms	$10^6 Y$ mhos
			Measurements from Seattle End.			
0	4.660	. . . .	0.0030	. . . . .	$4.660 /\underline{0°}$	$0.0030 /\underline{0°}$
200	5.388	0.001215	17.02	0.2712	$5.600 /\underline{15.82°}$	$341.3 /\underline{87.14°}$
320	5.557	0.001100	29.80	0.2670	$5.981 /\underline{21.71°}$	$537.7 /\underline{86.82°}$
400	5.686	0.001057	36.02	0.2650	$6.276 /\underline{25.04°}$	$666.9 /\underline{86.90°}$
512	5.813	0.001006	50.43	0.2628	$6.653 /\underline{29.10°}$	$847.0 /\underline{86.59°}$
824	6.147	0.000928	107.31	0.2575	$7.801 /\underline{38.00°}$	$1337.5 /\underline{85.40°}$
			Measurements from Fort Lawton End.			
0	4.660	. . . .	0.0030	. . . . .	$4.660 /\underline{0°}$	$0.0030 /\underline{0°}$
199.3	5.432	0.001214	17.09	0.2704	$5.641 /\underline{15.64°}$	$339.1 /\underline{87.11°}$
257.9	5.513	0.001141	20.23	0.2683	$5.815 /\underline{18.54°}$	$435.2 /\underline{87.34°}$
400.6	5.810	0.0010585	27.24	0.2643	$6.392 /\underline{24.64°}$	$665.9 /\underline{87.66°}$
596.3	6.023	0.0009588	38.46	0.2613	$7.013 /\underline{30.81°}$	$979.8 /\underline{87.75°}$
772.6	6.191	0.0008850	52.74	0.2617	$7.535 /\underline{34.76°}$	$1272 /\underline{87.62°}$
1008.6	6.404	0.0008314	73.88	0.2636	$8.293 /\underline{39.44°}$	$1672 /\underline{87.47°}$
1295.6	6.551	0.0007947	129.6	0.2645	$9.206 /\underline{44.64°}$	$2157 /\underline{86.56°}$

The complex values of Z and Y are given in the above table in the form of a scalar value and angle.

The values of r, L, g, C, and θ_Y as given in the above table are shown plotted as functions of the frequency in Figs. 4, 5, 6, 7, and 8. The dotted lines connect the observations made at the Seattle end and the full lines connect the observations made at the Fort Lawton end. In estimating the consistency of the results from the appearance of the curves, due regard must be paid to the greatly magnified scales used in some cases.

The quantities which enter more directly into the equations determining the manner of transmission of alternating currents than do the fundamental electrical properties themselves, are:

$$u = \sqrt{\frac{z}{y}} = \text{infinite-line impedance, ohms ;}$$

$$\theta_u = \frac{1}{2}\left(\theta_z - \theta_y\right) = \text{angle of infinite-line impedance;}$$

$$U = u \, /\underline{\theta_u}$$

α = real portion of V = attenuation constant; numeric per km.

β = imaginary portion of V = wave-length constant; radians per km.

$S = \dfrac{\omega}{\beta}$ = velocity of propagation; km. per sec.

$\lambda = \dfrac{2\pi}{\beta}$ = wave length; km.

FREDERICK E. PERNOT.

The values of the above quantities as determined from the measurements and in the units specified above are given in Table X.

TABLE X.

Transmission Constants for Alternating Currents.

f	a km. $^{-1}$	β km. $^{-1}$	u ohms	Θu	S km./sec.	λ km.
			Measurements from Seattle End.			
0	0.00011	0.00000	39000	00000	. . . . .	. . . . . .
200	0.02723	0.03421	128.10	$-35.66°$	36740	183.7
320	0.03312	0.04604	105.47	$-32.55°$	43680	136.5
400	0.03620	0.05362	97.01	$-30.93°$	46870	117.2
512	0.03995	0.06356	88.63	$-28.74°$	50620	98.86
824	0.04843	0.08994	76.37	$-23.70°$	57560	69.86
			Measurements from Fort Lawton End.			
0	0.00011	0.00000	39000	00000	. . . . .	. . . . . .
199.3	0.02730	0.03417	129.0	$-35.73°$	36650	183.9
257.9	0.03032	0.04015	115.6	$-34.40°$	40360	156.5
400.6	0.03635	0.05418	97.97	$-31.51°$	46460	115.96
596.3	0.04234	0.07126	84.60	$-28.47°$	52580	88.17
772.6	0.04717	0.08577	76.98	$-26.43°$	56600	73.25
1008.6	0.05263	0.10535	70.42	$-24.01°$	60150	59.64
1295.6	0.05822	0.12834	65.33	$-20.96°$	63430	48.96

TABLE XI.

Infinite-line Impedance of Sitka-Seattle Cable.
Measured at Sitka.

f cyc.	Conductance, mhos	Susceptance, mhos	U ohms and angle
22.18	0.002234	0.001873	$343.0\underline{/39.97°}$
33.59	0.002678	0.002235	$286.6\underline{/39.85°}$
39.80	0.002893	0.002410	$265.6\underline{/39.79°}$
46.58	0.003108	0.002585	$247.4\underline{/39.75°}$
56.41	0.003394	0.002816	$226.8\underline{/39.69°}$
81.44	0.004031	0.003306	$191.8\underline{/39.36°}$
95.47	0.004359	0.003532	$178.2\underline{/39.02°}$
131.09	0.005152	0.003994	$153.4\underline{/37.78°}$
161.78	0.005742	0.004262	$139.8\underline{/36.59°}$
203.1	0.006450	0.004597	$126.2\underline{/35.48°}$
245.8	0.007140	0.004892	$115.5\underline{/34.42°}$
296.0	0.007694	0.005025	$108.8\underline{/33.15°}$
384.3	0.008696	0.005315	$98.12\underline{/31.43°}$
476.5	0.009593	0.005492	$90.47\underline{/29.78°}$
613.8	0.01079	0.005491	$82.60\underline{/26.97°}$
739.2	0.01164	0.005382	$77.98\underline{/24.82°}$
859.0	0.01228	0.005195	$74.99\underline{/22.93°}$
1039.0	0.01296	0.004935	$72.09\underline{/20.84°}$
1184.0	0.01334	0.004794	$70.53\underline{/19.76°}$

In the above table the conductance and susceptance as tabulated are the two components of the reciprocal of U. The angle of U is to be counted as negative.

The attenuation constant a is shown as a function of the frequency in Fig. 9. The data obtained from the two sets of measurements are in such close agreement that a single curve suffices to represent all of the points.

FIG. 4.

Resistance Per Kilometer

Frequency
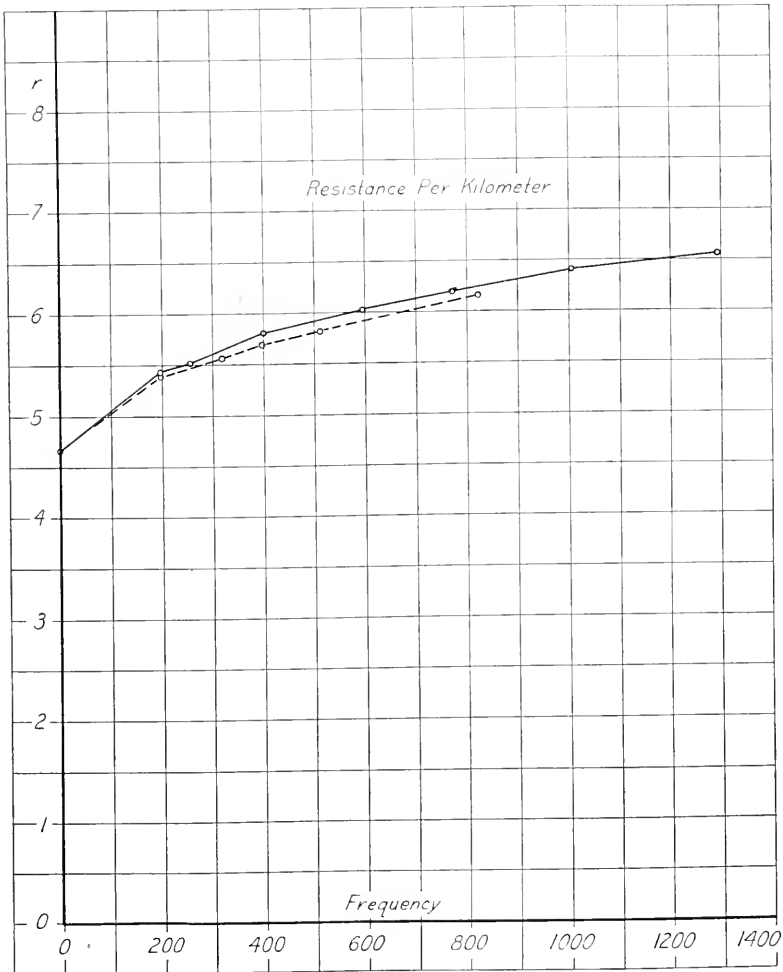
Fig. 10 shows the scalar value of the infinite-line impedance u. In addition to the values given in Table X it contains the values determined by measurements made at Sitka, Alaska, on the long cable (approximately 1700 kilometres) between there and Seattle.

As far as the tabulated frequencies are concerned, this constitutes an infinite length, or at any rate, a length sufficient to prevent conditions at the remote end from affecting the measured impedances

FIG. 5.

Self Inductance Per Kilometer

Frequency
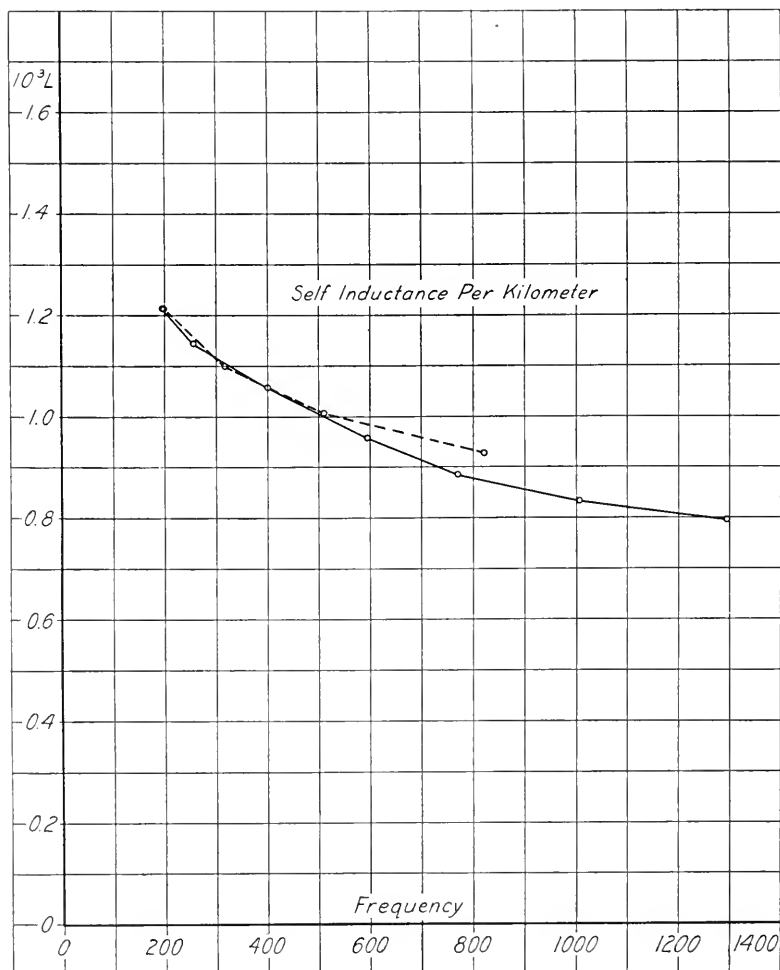
at the input end. The data obtained in these measurements at Sitka are given in Table XI. Because of the great length, a single determination with the impedance bridge gave the desired result immediately. Both in the case of u and of θ_u the agreement

between the values determined by the two impedance measurements on the short Seattle-Fort Lawton cable and by the single impedance measurements on the long Sitka-Seattle cable is excel-

FIG. 6.
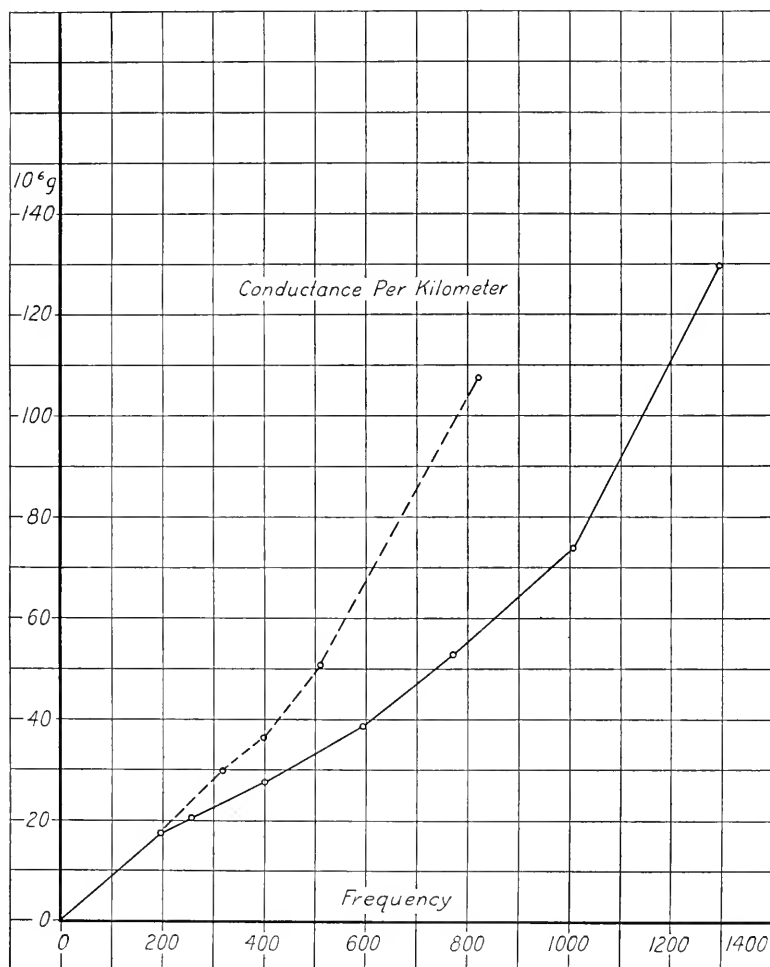
lent, indicating that the measurements are reliable and that the cables are similar electrically.

Fig. 11 shows the angle of the infinite-line impedance as a function of the frequency.

A further check on the accuracy of the results is obtained from the data in Table VI. From this data values of Z_a as determined by direct measurement when $Z_a = 100.01 + j\ 0.00000$ are

FIG. 7.
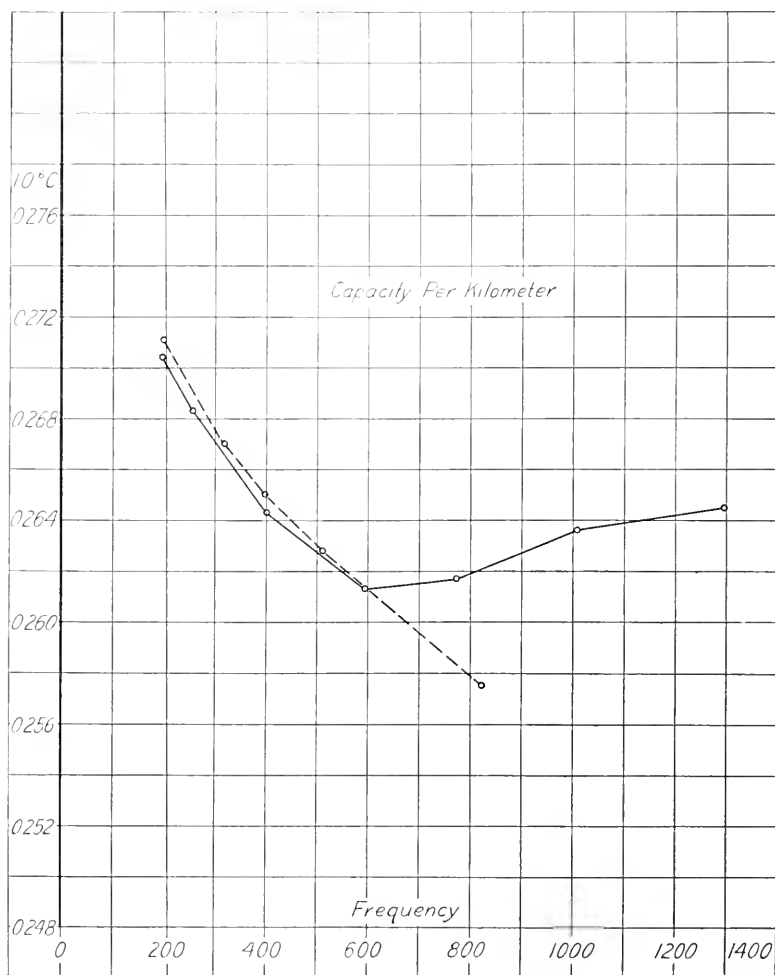
obtained. Using equation (11) and the transmission constants given in the second portion of Table X for the same frequencies as those at which Z_a was measured, the values of Z_a can be computed. A comparison of the computed and the directly measured

values can then be made. Table XII contains the results obtained by the two methods. In place of Z_a itself, the two components of its reciprocal are tabulated.

$$\frac{1}{Z_a} = g_a + j \omega C_a.$$

The greatest deviation between observed and computed values is slightly over two per cent., which is an amount at least four times what might reasonably be expected to be the possible error

TABLE XII.

Comparison of Measured and Computed Admittances when $Z_0 = 100.01 + j \ 0.000$. From data obtained at Fort Lawton end.

f	g_a measured	g_a computed	$10^6 \ C_a$ measured	$10^6 \ C_a$ computed
199.3	0.006200	0.006155	1.848	1.822
257.9	0.006431	0.006382	1.838	1.816
400.6	0.007236	0.007106	1.777	1.744
596.3	0.008816	0.008668	1.641	1.623
772.6	0.01062	0.01051	1.464	1.477
1008.6	0.01317	0.01319	1.164	1.192
1295.6	0.01561	0.01577	0.7752	0.7788

in the observations. This discrepancy, as well as the small, consistent deviations between the curves representing the line properties as determined from the two ends of the cable, undoubtedly arise from the fact that the cable is not homogeneous throughout its length. It is made up of two pieces, each having the same specifications as the other, but the two parts undoubtedly having slightly different properties because they were manufactured at different times. Such an explanation is sufficient to account for the differences observed, in view of the fact that the formulæ for the reduction of the observations presuppose complete uniformity. As they stand, the experimental results are undoubtedly of greater accuracy than can be hoped for in any analysis relating the observed electrical properties of the system to the fundamental physical constants and the dimensions.

ANALYSIS OF RESULTS AND TRANSMISSION CALCULATIONS.

An examination of the results given in the foregoing reveals important general facts. Without going into a detailed, rigorous

analysis of the whole problem, some things can be found out which are of general approximate application.

The resistance, as expected, increases with the frequency.

FIG. 8.
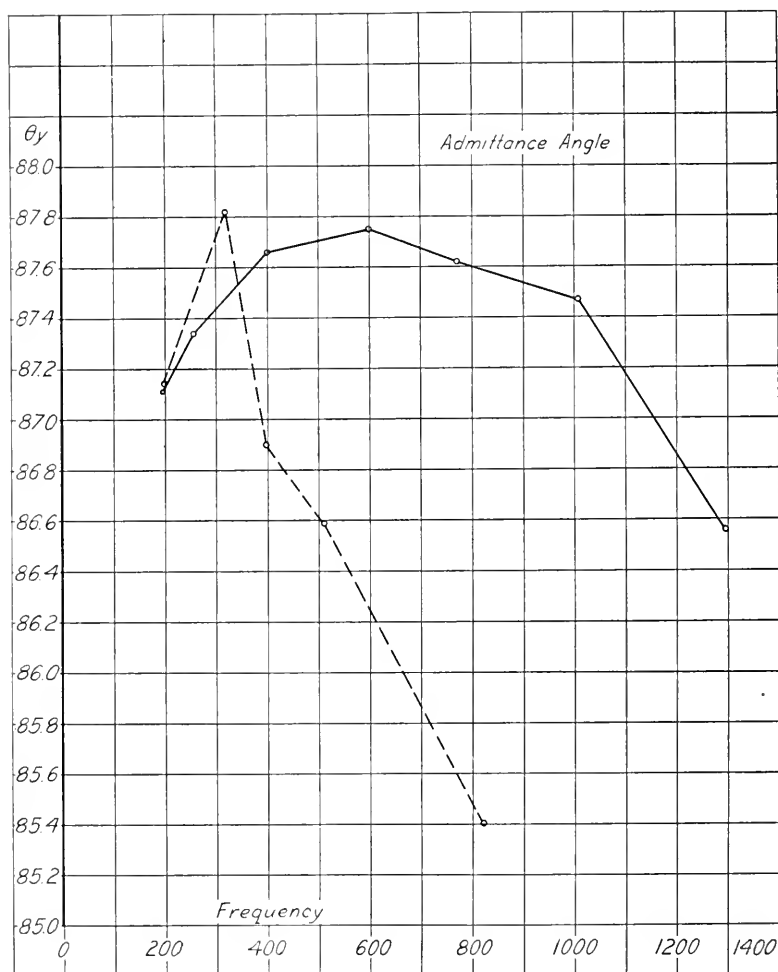
At the frequencies employed, only a very small increase in resistance should result from the so-called skin effect in the main conductor itself, so that the observed increase, which is considerable, must arise from causes associated with the steel armor and the

surrounding water.   The total resistance as observed is expressible as

$$r = r_o + \phi\,(\omega) \qquad\qquad (11)$$

in which

r_o = direct-current resistance

and

$\phi\,(\omega)$ = an increasing function of ω whose value is zero at zero frequency.

The direct-current resistance depends only upon the conductor itself, while the increase in resistance, $\phi\,(\omega)$, depends only upon the surroundings of the conductor. All submarine cables are subjected to similar water immersions, and also are similarly-arranged combinations of dielectric and steel armor.   The increase in resistance, $\phi\,(\omega)$, should then be approximately the same for most cables, regardless of what r_o may be.

When it is assumed that the increase in resistance is accounted for by the presence of a definitely localized short-circuited system in the vicinity of the main conductor, the equation for the apparent resistance takes the form (see Univ. of Calif. Publ. in Engineering, vol. i, "Alternating and Transient Phenomena in Coupled Electric Circuits," p. 171).

$$r = r_o + \cfrac{1}{a + \cfrac{b}{\omega^2}}$$

where a and b are constants depending upon the second system and the electromagnetic coupling between the two systems.   To this expression should be added a term representing the hysteresis loss in the steel armor.   This term is proportional to the frequency.   Another term proportional to the square of the frequency may be added to represent the first term in the series expansion for the eddy-current or skin-effect phenomena.   The final approximate form is then

$$r = r_o + \cfrac{1}{a + \cfrac{b}{\omega^2}} + c\omega + d\omega^2 \qquad\qquad (12)$$

The observed data can be very well represented by this equation when the constants a, b, c, and d are determined by least-square methods.   This shows that as far as the one quantity r is concerned, the hypothesis just made offers a satisfactory explanation

for the phenomena, but even so, this information does not aid materially in predetermining the resistance change for different sizes and kinds of cables. This latter requires that the effective

FIG. 9.
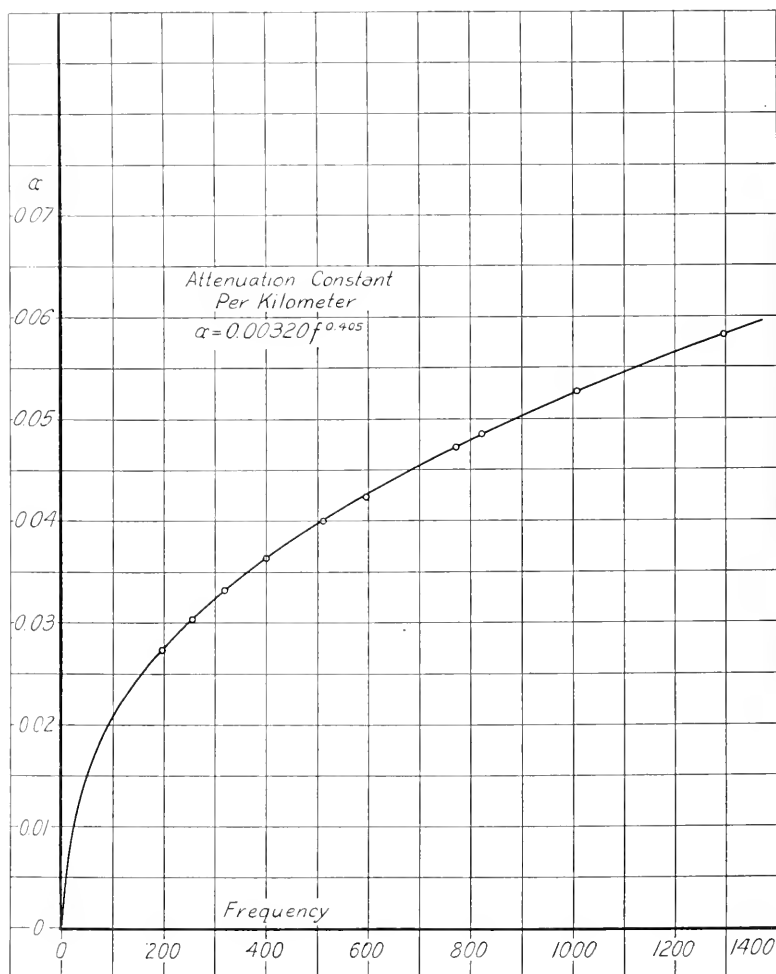
resistance be expressed in terms of the fundamental properties of the different components of the system. Without such detailed analysis, about the best that can be done is to accept equation (11), with ϕ (ω) as determined from the data submitted. The

observed increase is approximately 1.7 ohms per kilometre, at a frequency of 1300 cycles per second.

The total apparent self-inductance is determined by those factors which determine the change in resistance. The percentage

FIG. 10.
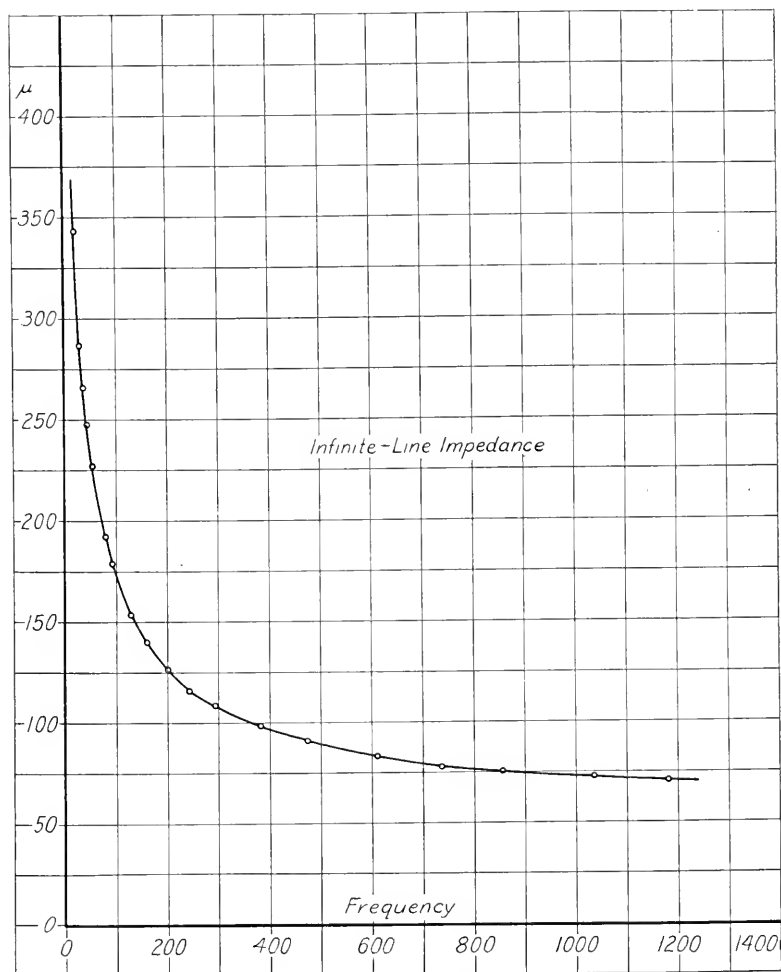
error in estimating the total self-inductance for any cable will then be much greater than that in estimating the total resistance, because the total resistance contains a constant component which is capable of accurate determination at the time of manufacture.

If the surroundings of the main conductor be again considered as constituting a definite closed electrical path, the equation representing the total self-inductance as a function of the frequency will be of the form (see the above-named reference),

$$L = L_o - \cfrac{1}{a' + \cfrac{b'}{\omega^2}} \qquad (13)$$

in which a' and b' are constants depending as before upon the electrical relations of the main conductor and the surrounding closed path. When these constants are determined empirically from the data given, the observations are represented very well, but relations which necessarily exist between a, b, a' and b' are not fulfilled. The non-fulfillment of these relations can indicate only what is obviously the truth—namely, that the combination of armor and surrounding water does not constitute a system equivalent in all respects to some simple closed circuit coupled electromagnetically to the main conductor. At zero frequency the return current distributes itself throughout the entire surrounding liquid and armor, but as the frequency increases, the return current becomes more and more concentrated in the immediate neighborhood of the cable. The same kind of analysis required to determine r accurately is also required to predetermine L.

For the same reasons that the increase in resistance with increasing frequency may be considered as approximately constant for different cables, the total self-inductance may be considered as approximately the same. This is so particularly in view of the fact that the observed self-inductance is much greater than that calculated on the basis of the return current being concentrated in the armor.

Little is to be said concerning the components of the admittance Y, other than to call attention to the fact that their variations with the frequency very closely meet the predictions given in the opening paragraphs. The effective alternating-current conductance, or leakage, is scarcely related to the simple dielectric resistance for direct current. It increases in approximate proportion to the frequency so that, with a practically constant capacity, the phase angle of Y is very nearly constant. For frequencies up to 1300 cycles per second, the change in the total effective capacity is only a few per cent.

When the four fundamental electrical constants are combined into the transmission constants given in Table X, marked discrepancies are to be noted between the experimental results and

FIG. 11.
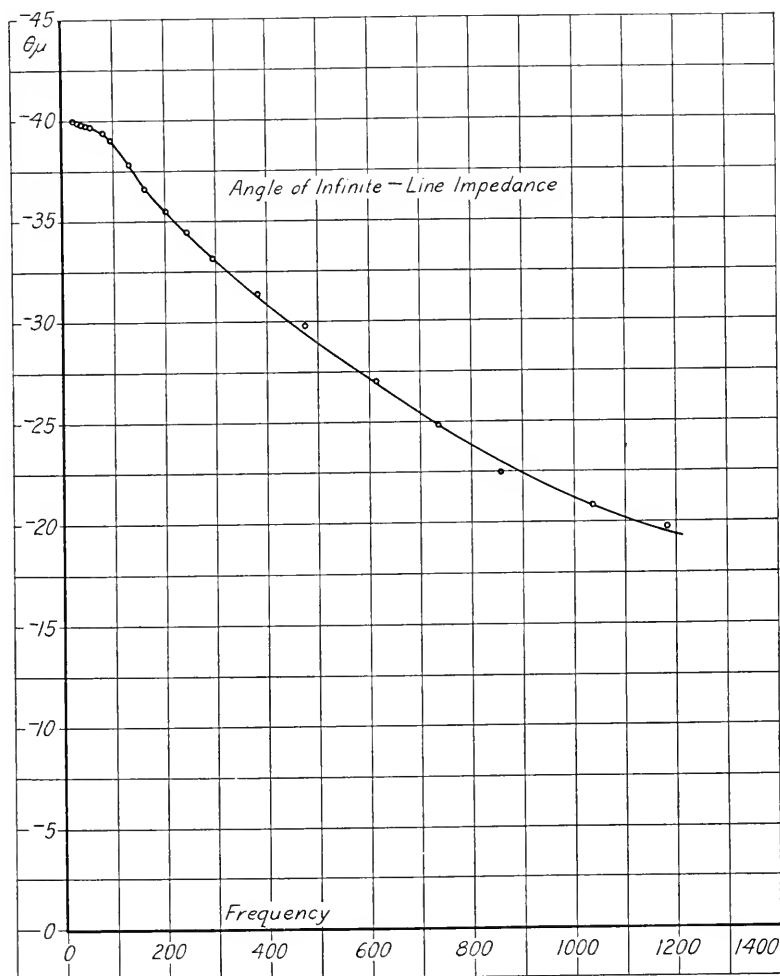
those given by the ordinary cable theory. The usual analyses of the performances of cables acted upon by alternating currents have neglected the self-inductance and leakage (effective alternating-current) and have also assumed r and C to be constant and

equal to their respective zero-frequency values. Such theory leads
to the simple expressions

$$\beta = a = \sqrt{\frac{1}{2}\, \omega\, r_o\, C_o}$$

$$u = \sqrt{\frac{r_o}{\omega\, C_o}}\; ; \theta_u = -\,45^\circ. \tag{14}$$

If, from the curves in Figs. 4 and 7, the zero-frequency values
be taken as

$$r = 4.66, \; C_o = 0.277 \times 10^{-6}$$

the approximate equations (14) become

$$\beta = a = 0.002014\, f^{\,0.5000}$$
$$u = 1636 f^{\,-0.5000}\; ; \theta_u = -\,45^\circ. \tag{15}$$

From the values of a, in Table X, an empirical equation as
derived by least-square methods is

$$a = 0.00320\, f^{\,0.405} \tag{16}$$

It is from this equation that the smooth curve in Fig. 9 is drawn.
The very satisfactory nature of the measurements is indicated
by the way the observations lie on the curve. It is to be noted that
the empirical equation makes a proportional to the 0.405 power
of the frequency instead of the 0.5000 power as given by the
approximate theory. It is rather remarkable that the empirical
equation represents the observations with such accuracy, in view
of the complicated way in which a truly depends upon the fre-
quency. Its true value is

$$a = \text{real portion of } \sqrt{(r + j\,\omega\,L)\,(g + j\,\omega\,C)}$$

where, r, L, g, and C are functions of the frequency (or ω) as
shown by the curves in Figs. 4 to 7, inclusive.

Table XIII shows for comparison the measured values of a
and also the values computed by equation (15). For all of the
frequencies shown, the observed values of a are smaller than the
values computed by the approximate theory on the basis of the
zero-frequency values of r and C. This can only be caused by
the self-inductance, L, since the per cent. increase of resistance
with frequency is much greater than the per cent. decrease in
capacity at any frequency. This fact is readily appreciated after
inspecting Table IX, where the angle of the impedance Z is seen

to reach 45 degrees at a frequency of 1300 cycles per second, in-
stead of being 0 as given by the approximate theory.   Table XIII
also contains the observed and the calculated values of the in-
finite-line impedance.   Because of the increase in r with fre-
quency and also because of the self-inductance, the observed
values of u are much greater than the approximate calculated
values.   Since the amount of power delivered to the cable at a
given voltage is inversely proportional to u, and since the safety
of the cable requires that the impressed voltage be definitely
limited, it appears impossible to safely supply as much power to
the cable as is indicated by the approximate calculations.   If the
impressed voltage be c, then the power input to the long cable is

$$P = \frac{c^2}{u} \cos \theta_u \qquad (17)$$

The approximate theory gives $\theta_u = -45$ degrees, a constant, but the
experiments show that θ_u is very much less numerically than 45
degrees when the frequency reaches 1000 cycles per second, or
beyond.   As an illustration, if the impressed emf. be limited to
50 volts, the power inputs, as based upon the observed and calcu-
lated values of U, are, for a frequency of 1295.6 cycles per second,

$$P_{obs} = \frac{50^2}{65.33} \cos(-20.96°) = 35.7 \text{ watts}$$

$$P_{cal} = \frac{50^2}{45.5} \cos(-45.0°) = 38.9 \text{ watts}.$$

TABLE XIII.

*Comparison of the Measured Values of the Transmission Constants and the Values
Calculated by the Approximate Theory which Neglects L and G.*

f	a obs.	a cal.	u obs.	u cal.	θ_u obs.
199.3	0.02730	0.02843	129.0	115.9	$-35.7°$
200	0.02723	0.02848	128.1	115.7	$-35.7°$
257.9	0.03032	0.03234	115.6	101.9	$-34.4°$
320	0.03312	0.03602	105.5	91.4	$-32.6°$
400	0.03620	0.04027	97.0	81.8	$-30.9°$
400.6	0.03635	0.04031	98.0	81.7	$-31.5°$
512	0.03995	0.04556	88.6	72.3	$-28.7°$
596.3	0.04234	0.04917	84.6	67.0	$-28.5°$
772.6	0.04717	0.05598	77.0	58.9	$-26.4°$
824	0.04843	0.05781	76.4	57.0	$-23.7°$
1008.6	0.05263	0.06394	70.4	51.5	$-24.0°$
1295.6	0.05822	0.07248	65.3	45.5	$-21.0°$

Even though the calculated impedance is much lower than the observed, the calculated power is not much larger than the observed because of the fact that the true power factor (cos–20.96°) is considerably greater than the calculated power factor (cos–45°).

As an illustration of the use of the foregoing data, calculations relative to the possibilities of signal transmission by alternating currents will be shown. The receiving-end condition which insures the reception of maximum power is that the load impedance Z_o be equal in scalar value to u, and also that it have an angle equal to, and opposite in sign, to θ_u. (See page 221, " Electrical Phenomena in Parallel Conductors," vol. i.) The calculation of the transmission phenomena is much simplified, however, when it is assumed that $Z_o = U$. When this is the case, the received power is slightly less than when the above optimum relation is fulfilled, but in a system with such an extremely low efficiency as a cable, this small difference is negligible. The general formula relating input voltage E and received voltage E_o is

$$E = E_o \left(\cosh Vl + \frac{U}{Z_o} \sinh Vl\right) \tag{18}$$

When $Z_o = U$, this reduces to

$$E = E_o (\cosh Vl + \sinh Vl) = E_o \varepsilon^{Vl} \tag{19}$$

Since, in this problem, it is only the effective scalar values of voltage which are of interest, the rotation of the vectors as produced by the imaginary portion of Vl may be neglected, giving

$$e = e_o \varepsilon^{al} \text{ or } e_o = e\varepsilon^{-al} \tag{20}$$

as the equation for scalar values when there is no reflection at the load end ($Z_o = U$).

As stated previously, e is limited by considerations of safety to 50 volts. Present possibilities in the construction of vacuum-tube amplifiers are such that an electromotive force of 10^{-7} volts is about the minimum value which will produce satisfactory signals at frequencies between 50 and 1500 cycles per second. By taking $e = 50$ and $e_o = 10^{-7}$, and using equation (20), the greatest distance over which signals can be transmitted satisfactorily can be calculated when a is known. The equation is

$$l = \frac{1}{a} \ln \frac{e}{e_o} = \frac{1}{Ma} \log \frac{e}{e_o} \tag{21}$$

where $M =$ modulus.

The power input may be computed by equation (17).

Table XIV contains the results of calculations made for the Alaskan cable whose properties have been given in the foregoing. For this cable, since

$$a = 0.00320 \ f^{0.405},$$

equation (21), after substituting 5×10^8 for $\frac{e}{e_o}$, becomes

$$l = \frac{6259.4}{f^{0.405}}$$

$$\log l = 3.79653 - 0.405 \log f \tag{22}$$

The last column contains values of the distance for which $\varepsilon^{al} = 10$, or those distances in which the voltage decreases by a factor $\frac{1}{10}$. If l_1 designate this distance, then

$$l_1 = \frac{1}{Ma} \tag{23}$$

TABLE XIV.

Transmission Data for Alaskan Cable.

Calculated from observed properties for $e = 50$ and $e_0 = 10^{-7}$ volts, u and θu from Figs. 10 and 11.

f	α per km.	u ohms	θ_u deg.	P watts	l km.	l_1 km.
50	0.01561	237	$-39.7°$	8.1	1284	147.6
100	0.02066	172	$-38.8°$	11.3	969	111.4
200	0.02736	126	$-35.5°$	16.1	732	84.2
300	0.03224	107	$-33.0°$	19.6	621	71.4
400	0.03622	96	$-30.8°$	22.4	553	63.6
600	0.04269	83	$-27.1°$	26.8	469	53.9
800	0.04796	76	$-23.8°$	30.1	418	48.0
1000	0.05250	72	$-21.2°$	32.4	382	43.9
1200	0.05652	70	$-19.3°$	33.7	354	40.7

It is hardly desirable to use frequencies below 50 cycles per second, for then in rapid signaling, each signal element would contain too few complete cycles to permit of selectivity in reception. For this particular cable, if 50 cycles per second be considered as the lowest usable frequency, then the greatest distance over which this method of signaling will produce 10^{-7} volts at the receiving end is 1284 kilometres (approximately 800 miles). In all cases the amount of power required for sending is small.

Description of actual trials of this method of signaling is given later.

As a further illustration of the foregoing analyses, calculations for a typical Atlantic cable will be attempted. For this illustration the cable described by Squier, " On an Unbroken Alternating Current for Cable Telegraphy," Proceedings of the Physical Society of London, vol. xxvii, Part V, page 553, has been chosen. The data given for it are

> Length = 2164 nautical miles.
> Total resistance = 4895 ohms.
> Total capacity = 914.1 microfarads.
> The dielectric is gutta percha.

Taking from Bowditch, 1918, the value 6080 feet per nautical mile, the above data gives for the zero-frequency properties

> $r_o = 1.2206$ ohms per kilometre.
> $C_o = 0.22794$ microfarads per kilometre.
> Total length = 4010.3 kilometres.

This is all of the data available. Approximate values of the four fundamental electrical properties at different frequencies must be found in order to calculate the transmission constants.

The capacity may be considered as constant, independent of the frequency, since this was found to be very nearly the case for the Alaskan cable. For the Alaskan cable the angle of the admittance, θ_y, was found to be practically constant, with a mean value of 87.0 degrees. This is for a rubber insulation, which undoubtedly is poorer than a gutta-percha insulation. It is probable that for the latter an angle of 88 degrees would be nearer the truth, but this cannot be definitely asserted without some comparative study of the two kinds of dielectric. The value of 88.0 degrees will, however, be accepted as the basis for this calculation. The admittance then is

$$Y = (\omega C \cosec 88°) \,\underline{/\,88.0°}$$
$$= \omega C \cot 88° + j \omega C \qquad (24)$$

since $C = C_o$

For the resistance, the direct-current value r_o increased by $\phi (\omega)$, as determined for the Alaskan cable, is the best approximation possible. $\phi (\omega)$ can be found for any frequency from Fig. 4 by subtracting the direct-current value (4.660 ohms) from the

appropriate ordinate of the curve. For the self-inductance the values given by Fig. 5 are the only ones available to apply to the problem in hand.

Table XV gives the quantities required in the calculation of the transmission constants. In it

$\phi\,(\,\omega\,)$ was taken from Fig. 4.

$r = 1.2206 + \phi\,(\,\omega\,)$.

L was taken from Fig. 5.

The table also contains the scalar values and angles of the derived quantities Z and Y.

TABLE XV.

Approximate Values of Cable Properties for Atlantic Cable, Based upon its Direct-current Resistance and Capacity and the Alaskan Cable Data.

$C = 0.22794 \times 10^{-6}$ farads per km.

$r_0 = 1.2206$ ohms per km.

$\Theta_y = 88.0$ degrees.

f	$\phi(w)$	r	L	Z	Y
0	0	1.22	....	$1.22\ \underline{0^\circ}$	....
50	0.07	1.29	0.00144	$1.37\ \underline{19.3^\circ}$	$0.0000717\underline{/88.0^\circ}$
100	0.30	1.52	0.00134	$1.74\ \underline{/29.0^\circ}$	$0.0001433\underline{/88.0^\circ}$
200	0.73	1.95	0.00121	$2.47\ \underline{/38.0^\circ}$	$0.0002866\underline{/88.0^\circ}$
300	0.95	2.17	0.00112	$3.03\ \underline{/44.2^\circ}$	$0.0004299\underline{/88.0^\circ}$
400	1.11	2.33	0.00105	$3.52\ \underline{/48.6^\circ}$	$0.0005733\underline{/88.0^\circ}$
600	1.35	2.57	0.00095	$4.41\ \underline{/54.3^\circ}$	$0.0008600\underline{/88.0^\circ}$
800	1.54	2.76	0.00088	$5.21\ \underline{/58.0^\circ}$	$0.001146\underline{/88.0^\circ}$
1000	1.71	2.93	0.00083	$5.98\ \underline{/60.7^\circ}$	$0.001433\underline{/88.0^\circ}$
1200	1.86	3.08	0.00080	$6.77\ \underline{/63.0^\circ}$	$0.001720\underline{/88.0^\circ}$

By using equation (6) in conjunction with equation (24) and the values given in Table XV, the transmission constants a, u, and θu are found to be as given in Table XVI. The distance l is calculated by equation (21) for $c = 50$ and $c_0 = 10^{-7}$ volts. The power P is calculated by equation (17). The last column contains the quantity l_1, the distance over which the voltage and current change by a factor $\frac{1}{10}$. l_1 is given by equation (23).

Fig. 12 shows the quantities given in the table. The values of a are represented with sufficient accuracy by the equation shown on the curve. The curves, naturally, are similar to those for the Alaskan cable. The attenuation is much less and, on

Table XVI.

Calculated Transmission Data for Atlantic Cable.

From data in Table XV and for $e = 50$ and $e_0 = 10^{-7}$ volts.

f cyc.	α per km.	u ohms.	θu deg.	P watts	l km.	l_1 km.
50	0.00587	138	$-34.3°$	14.9	3415	393
100	0.00825	110	$-29.5°$	19.8	2429	279
200	0.01210	93	$-25.0°$	24.4	1656	190
300	0.01461	84	$-21.9°$	27.6	1371	158
400	0.01663	78	$-19.7°$	30.0	1205	138
600	0.01988	72	$-16.8°$	33.4	1008	116
800	0.02258	67	$-15.0°$	35.8	887	102
1000	0.02499	65	$-13.7°$	37.6	802	92
1200	0.02706	63	$-12.5°$	38.9	740	85

account of the lower resistance and consequent greater proportionate effect of the self-inductance, the angle of the infinite-line

Fig. 12.
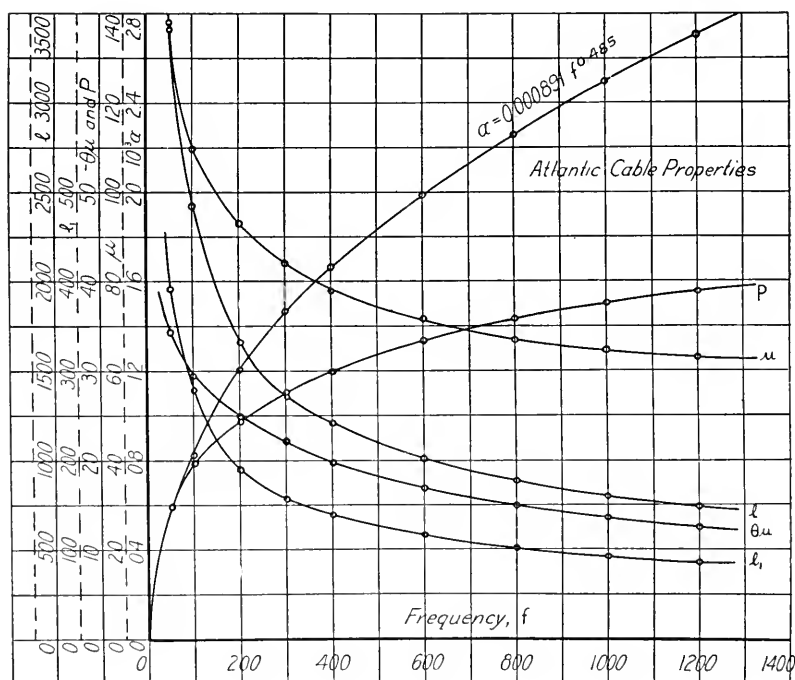
impedance is more nearly zero. At 50 cycles per second, the maximum workable distance is found to be 3415 kilometres. This

is on a basis of 10^{-7} volts at the receiving end. The total length of this cable across the Atlantic is 4010 kilometres, so that it appears that the scheme of signaling with alternating currents is just possible for this cable. A slight decrease in frequency would decrease the attenuation sufficiently to still leave 10^{-7} volts at the full distance of 4010 kilometres. Since $l_i = 393$ km. for $f = 50$ cycles per second (this being the distance for a 10-to-1 ratio of voltage or current), an improvement in the amplification at the receiving end by

$$\log_{-1}\left(\frac{4010 - 3415}{393}\right) = 33$$

times would also suffice to make transmission at a frequency of 50 cycles per second possible.

The above results should be highly significant in suggesting improvements in the already overworked Atlantic cables. The errors arising from the approximate manner of finding the cable properties should not be sufficient to vitiate the above conclusions.

TRIALS OF ALTERNATING CURRENT TRANSMISSION.

In addition to the measurements of the cable properties as described in the foregoing, a number of trials were made of the transmission of alternating currents over cables, both over the long cable between Sitka, Alaska, and Seattle, Washington, and over shorter cables between various towns in southeastern Alaska. The results which could be obtained in tests of this kind were, of course, entirely dependent upon the degree of amplification which was obtained in them. As it naturally was impossible, in the limited time available for this work, to do a great deal towards the development of powerful low-frequency amplifiers, the results here given cannot be considered as the best possible.

The first trials were made over the long cable and, as a preliminary step, calculations based upon the fundamental cable properties as previously determined, were made in order to ascertain approximate values of received voltage at the different frequencies. The total cable length between Sitka and Seattle is 1751 kilometres (1088 miles). The impressed electromotive force, both as used in the tests and in the calculations, was 50 volts. The results of the calculations are given in Table XVII, in which

the received voltage c_o is that which occurs when the load impedance equals the infinite-line impedance U. The empirical equation for the attenuation constant a was used. At these very low frequencies no observations had been made to determine the cable properties, so that the empirical formula serves as a means of interpolating between the zero-frequency value zero and the value of a found at 200 cycles per second. For such low frequencies as are involved, the empirical equation for a gives values greater than does the approximate equation (15), whereas the reverse is true at the higher frequencies shown in Table XIV. The following data shows the differences between the two equations for the frequencies under consideration.

f	$a = 0.00320 f^{0.405}$	$a = 0.00201 f^{0.500}$
cycles per second	Empirical	Approximate
10	0.0081	0.0064
15	0.0096	0.0078
20	0.0108	0.0090
25	0.0118	0.0101
30	0.0127	0.0110
35	0.0135	0.0119
50	0.0156	0.0142

The difference between the two values is as much as 20 per cent. at the lowest frequency. By equating equations (15) and (16) and solving for f, the frequency at which both equations give the same result is found to be 65 cycles per second. It is probable that at the lowest frequencies the true value of a is nearer to that given by the approximate equation than to that given by the empirical equation, because at the low frequencies the self-inductance does not play an important part. The true value of a and the empirical equation become asymptotic before a frequency of 200 cycles is reached, because at this frequency the measurements began and the empirical equation was deduced so as to fit the facts. The conclusion is certain that, at frequencies below 50 cycles per second, the empirical equation gives values of a which are too high. It is equally certain then, that the conditions represented in Table XVII are at least as bad, if not worse, than the true state of affairs. The true values of c_o may be several times those shown.

For the trials of transmission over the long cable, the generator and sending apparatus was installed at Sitka and the amplify-

ing and receiving apparatus at Seattle. For amplification a tuned, vacuum-tube amplifier with any desired number of stages up to six was developed. It consisted of the standard type (V.T.–2) Signal Corps transmitting tubes interconnected by transformers which were arranged to be tuned by adjustable condensers connected to their secondary windings. A voltage amplification of from 6 to 8 per stage was obtained at frequencies of from 20 to 40 cycles per second. For six stages a total voltage amplification of from 50,000 to 250,000 was thus obtained. Because of the fact that no success attended any of the trials made over this long cable, a detailed description of the amplifier and receiving apparatus is not necessary here.

TABLE XVII.

Calculated Attenuation Constant and Received Voltage for Seattle-Sitka Cable.

$\alpha = 0.00320 \, f^{0.405}, \; e_o = e \, \varepsilon^{-al}, \; l = 1751, \; e = 50.$

f	al	e_o
10	14.2	33.0×10^{-6} volts
15	16.8	2.61×10^{-6} volts
20	18.8	0.328×10^{-6} volts
25	20.6	0.0553×10^{-6} volts
30	22.2	0.0114×10^{-6} volts
35	23.6	0.0027×10^{-6} volts
50	27.3	0.00007×10^{-6} volts

It was at first planned to use a telephone receiver to detect signals of audible frequency, but a consideration of the results given in Table XVII showed conclusively that it would be hopeless to detect received currents of frequencies above 35 cycles per second and that, therefore, a signal of audible frequency could not be obtained. For use over the range of frequencies between 15 and 35 cycles per second a vibration galvanometer was selected. This instrument was kindly loaned for the duration of the experiments by the Electrical Engineering Department of the University of Washington. In addition to high sensitivity at the low frequencies it had the additional advantage of being very selective as to frequency, so that it should be an aid in minimizing the effect of " stray " disturbances. The galvanometer resistance was 49 ohms; excellent adjustment of sensitivity was obtained by shunting its terminals with a known resistance.

A typical record of one of the numerous trials is given here:

Date of trial, August 23, 1919.
Sending station, Sitka, Alaska, cable office.
Impressed electromotive force, 50 volts.
Frequency, 20 cycles per second.
Approximate input current, 0.15 amperes.

At Seattle, with the amplifier and galvanometer placed in a room about 15 metres distant from the cable office, it was found necessary to have all sounders and relays shut off because of the disturbances transmitted electromagnetically from them. When these instruments (sounders and relays) were not in operation, the amplifier by itself was entirely quiet, with no tendency to oscillate, as indicated by the galvanometer remaining steadily at zero. The amplifier and galvanometer were both tuned to 20 cycles per second.

With the cable connected to the input terminals of the amplifier, and when voltage was not impressed upon the cable at Sitka, the galvanometer gave a very unsteady deflection, averaging 2 centimetres on the scale when the galvanometer terminals were shunted by 0.2 ohms. This shunt reduced the galvanometer sensitivity to about $\frac{1}{250}$ of normal. No change in the unsteady deflection could be detected when alternating current was sent from Sitka. The observed deflection could only have been caused by " stray " electromotive forces induced in the cable system by street-car and power circuits, or by some natural, but obscure, magnetic or electric effects in the long cable itself. The cable office being in the midst of a busy portion of Seattle, it is known that the former influences were present, while it is not likely that natural magnetic or electrical variations, of such abruptness as to affect a tuned vibration galvanometer, connected to the cable through several stages of transformers, are to be found. Accurate information concerning this matter is needed, however. Calibration of the amplifier and galvanometer at the time of this test showed that at 20 cycles per second an input to the amplifier of 10^{-3} volts was necessary to produce the observed 2-centimetre deflection. The stray phenomena at the office cable terminals were, then, of this same order of magnitude, *viz.*, 10^{-3} volts, and probably were several times this amount, since in the calibration the frequency supplied was steady and equal to that

for which the galvanometer was tuned, which is not the case with the strays. From Table XVII it is seen that the received voltage to be expected is only 0.328×10^{-6} volts, a value only $\dfrac{1}{3000}$ of that arising from strays. It would obviously be impossible, therefore, to detect the small steady deflection in the midst of erratic stray deflections 3000 times its magnitude. With the galvanometer unshunted, or at normal sensitivity, the deflection for the steady alternating voltage of the above amount would have been

$$250 \times \frac{0.328 \times 10^{-6}}{10^{-3}} \times 2 \text{ cm.} = 0.16 \text{ cm.}$$

In the absence of stray disturbances, this amount could easily have been detected.

Since so much stray disturbance was encountered in the Seattle office building, it was decided to remove the amplifier and galvanometer to the shore-end of the sea cable, thereby eliminating about 400 metres of double-conductor, lead-covered cable between the shore-end and the Seattle office. Fig. 13 shows the

FIG. 13.
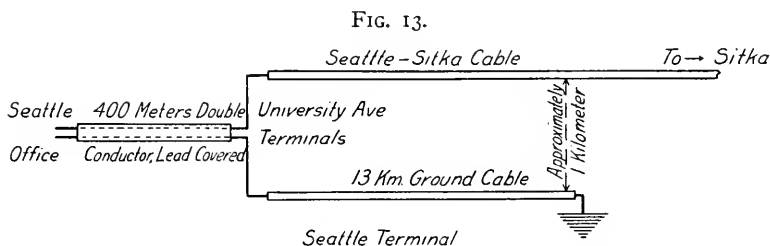
arrangement of the cable and ground connections at the Seattle end. Ground connection was made through approximately 13 kilometres of the standard type of submarine cable running out from Seattle into Puget Sound. The outer end of this cable and the attached ground contact is about 1 kilometre distant from the main Sitka-Seattle cable. Between the University Avenue shore terminal of the sea cable and the water, both the Sitka and the ground cables pass for approximately 100 metres beneath pavements and wharves.

With the amplifier and galvanometer adjusted as in the preceding test it was found that, when connection was made to the University Avenue cable terminals, a shunt resistance to the

galvanometer of 12 ohms was required to reduce the deflections caused by stray disturbances to 2 centimetres. Since for this same deflection a shunt of 0.2 ohms was required in the Seattle office building, it appears that the disturbances coming from the cables are only about $\frac{1}{50}$ of those reaching the office. According-ing to the calibration cited, the above corresponds to about 20×10^{-6} volts, which, as stray disturbance, is still about 60 times the alternating voltage of this same frequency which could be received from Sitka.

A series of results similar to those given above were obtained at different times, after which it was decided that it would be useless to attempt reception at the Seattle end. On account of the limited time available it was not possible to interchange apparatus and thus attempt transmission in the opposite direction. The amplifier and galvanometer were taken to Sitka, however, and there it was found that, because of the absence of extensive city power systems, very little disturbance could be detected. The small disturbances which were observed could very well have been caused by a low-power alternating-current lighting circuit which passed within 50 or 75 metres of the testing room.

In any practical application of this method of alternating-current signaling, great care will be required to avoid any local sources of disturbances in those cases where, on account of great cable length, a high degree of amplification becomes necessary.

Because of the failure to transmit alternating currents over the long Sitka-Seattle cable, and because other work required the presence of the entire party in Alaska, arrangements were made to conduct further experiments with alternating currents over the shorter lengths of cable extending from Sitka to other points in southeastern Alaska. These tests occupied the first two weeks in October, 1919, and in them alternating currents of frequencies from 50 to 700 cycles per second were satis-factorily transmitted and received over distances from 300 to 700 kilometres.

For these trials the amplifier was altered slightly in order to meet the conditions imposed by the higher frequencies which could be transmitted over these shorter lengths of cable. In its modified form an amplification of approximately 14.5 per stage, throughout the above range of frequencies, was obtained. With

the four stages available, a total voltage amplification of 40,000, or a corresponding power amplification of 16×10^8, was thus available. This is the maximum amplification possible when the load, cable output, and amplifier input and output impedances are so related as to give the best results. During the tests it is probable that the total voltage amplification actually secured was only about 20,000 or 30,000 instead of 40,000, because the several conditions required for maximum effectiveness could not be met exactly.

The cable network over which the experiments were made is as shown in Fig. 14, where the distances in kilometres between the various stations are shown. In the tests the generator was at

FIG. 14.
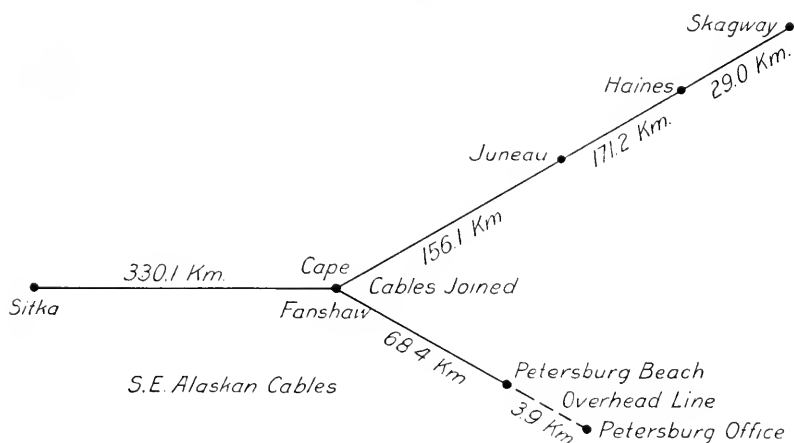
Sitka, while the amplifier and receiving apparatus were taken to the various points. At Cape Fanshaw the receiving set was connected to the Sitka cable after the other two branch cables had been disconnected. During all subsequent tests at the other points the three cables were joined at Cape Fanshaw, so that the received voltage was somewhat decreased because of the additional load imposed on the system by the branch cable. When the separate branches are of such length that reflected waves are negligible in comparison with the main waves, then the exact effect of this branching is to reduce all currents and voltages in the two branches to $\frac{2}{3}$ of the values they would have in the case of transmission over a single cable of a length equal to the distance between sending and receiving stations via the junction point. This reduc-

tion in voltage for all tests except that at Cape Fanshaw is taken account of in Table XVIII, which contains values of received voltages as calculated for the different points and different frequencies included in the experiments.

TABLE XVIII.

Calculated Values of Received Voltage.

For Cape Fanshaw, $e_0 = 50 \, \varepsilon^{-al}$

For all others $\qquad e_0 = \dfrac{2}{3} \times 50 \, \varepsilon^{-al}$

$$\alpha = 0.00320 \, f^{0.475}$$

The values given are expressed in microvolts.

Frequency	Station and distance				
	Cape Fanshaw 330.1	Petersberg Beach 398.5	Juneau 486.2	Haines 657.4	Skagway 686.4
50	290,000	66,000	17,000	1,200	740
75	116,000	22,000	4,400	190	110
100	55,000	8,900	1,400	42	**23**
125	29,000	4,100	560	12	6.0
150	16,000	2,000	240	3.7	1.8
200	6,000	610	**56**	0.52	0.23
300	1,200	88	5.2	0.021	0.0082
400	320	**18**	0.75	0.0015	0.00053
500	100	4.6	0.14	0.00016	0.000051
700	**12**	0.46	0.0085	0.000004	0.00000095

In Table XVIII the values corresponding to the highest frequencies satisfactorily received at the several stations are printed in heavy type. Were the amplifier and telephone receiver used in connection therewith of the same sensitivity at the different frequencies, these limiting values of voltage would all be equal provided the empirical equation for the attenuation constant a truly represents the facts. Since this equation was determined so as to agree with the facts as determined by experiment, no error of consequence need be expected in the calculations. As a matter of fact, all of those limiting voltages shown in the table are nearly constant. Had time permitted of a greater number of observations and a calibration of the amplifier for each, it is likely that a still greater uniformity in these results would have been obtained. The average of the several figures shown gives

Average received voltage for good signals with 4-stage amplifier = 24 microvolts.

For receiving the signals a standard, high-impedance Baldwin radio head set with double receivers was used. By good signals are meant those which were distinctly audible with the telephone receivers lying on a table at a distance of one metre from the observer. With the telephones on the head in the ordinary manner, this gives very good signals, indeed.

With the receiving apparatus as used, it is unquestionable that a received electromotive force of 5 microvolts would in all cases produce signals of ample intensity. It is, further, entirely possible to construct an amplifier 50 or 100 times as powerful as the one used throughout these tests, because, for the one used, such apparatus as was available had to be used instead of apparatus especially designed for the purpose. In addition, the amplifier had to be carried about from place to place and set up hurriedly in whatever place could be found in the various cable offices. All of these things conspire to prevent the maximum effectiveness in the use of such an apparatus.

The only thing which could prevent the use of a considerably greater degree of amplification than that employed is excessive extraneous, or stray, disturbances. The experiences met with in these tests showed that trouble of this nature can be avoided by taking the proper precautions. The amplifier cannot be used in the vicinity of power systems, and the cable must not pass close to such systems. It is considered quite certain that most of the disturbances are produced by electromagnetic induction and earth currents arising from grounded systems; conditions which make effective shielding practically impossible. With a cable in the open sea or everywhere at a distance of at least 2 or 3 kilometres from overhead power systems or of 10 or 12 kilometres from earth-return power systems, no difficulties should be expected.

Accepting, then, 5 microvolts as a sufficient amount to produce good signals with the amplifier used, and further, accepting the possibility of 50 or 100 times the amplification actually attained, it becomes possible to produce good signals with a received electromotive force of from 5×10^{-8} to 10^{-7} volts. It is in this way that the basic value of 10^{-7} volts was obtained for use in the calculation of the data given in Tables XIV and XVI.

A summary of the notes taken during the several trials of alternating-current transmission and reception is given in the

following table. The data contained in Table XVIII should be considered along with these notes:

TABLE XIX.

Notes on Observations Taken in Trials of Alternating-Current Transmission.

Date of tests, October 1 to October 15, 1919.
Sending station, Sitka, Alaska.
Generator electromotive force, 50 volts.

AT CAPE FANSHAW (330.1 km.).

Juneau and Petersberg cables disconnected.
Using a standard, low-impedance, bi-polar telephone receiver, readable signals were obtained at 300 cycles per second without amplification. Very loud signals of this frequency were obtained with one or more stages of amplification.
At 500 cycles per second the signals were just audible without amplification. Good signals were received with 2 and 3 stages of amplification, and very loud signals with 4 stages.
At 700 cycles a very steady, clear note which produced excellent signals was obtained with 4 stages of amplification.

AT PETERSBURG OFFICE (402.4 km.).

All cables interconnected at Cape Fanshaw.
Amplifier installed at cable office, which connects with the beach end of the cable through 3.9 km. of overhead line. Ground connection at the office.
Excessive inductive interference from surrounding power circuits was encountered, which made tests at this location impossible.

AT PETERSBERG BEACH (398.5 km.).

Amplifier mounted in open air at the cable terminal.
Excellent reception with 2 stages at 150 cycles.
At 200 cycles very loud signals were obtained using 3 and 4 stages; strong signals at 300 cycles with 3 stages.
With 4 stages good signals were received at 400 cycles.
All of the tests were satisfactory in every respect. No trouble from stray disturbances was encountered.

AT JUNEAU (486.2 km.).

Amplifier installed in cable office. Some interference from power circuit, which produced a distinct hum in the receiver.
The 100-cycle note could be heard all over the room with 4 stages of amplification, was very good with 3 stages, and produced good readable signals with 2 stages.
At 150 cycles the power-line interference was disturbing, but very good signals were obtained with 4 stages of amplification.

At 200 cycles satisfactory signals were obtained, but the interference still persisted.

The 250-cycle note could be heard distinctly, but beats between it and some harmonic in the power system prevented satisfactory reading of signals. (In Table XVIII the limiting voltage for the Juneau test should, therefore, be considerably less than the 56 microvolts as given for 200 cycles.)

During the experiments at Juneau a satisfactory trial was made of receiving direct-current signals from Petersberg on the regular cable instruments and at the same time receiving 100-cycle signals from Sitka.

AT HAINES (657.4 km.).

At Haines direct connection with Sitka was established by connecting through the Juneau office, but the two cables are not normally operated in this way.

Very loud 50-cycle signals were received with 4 stages. For a duration of several minutes the regular station operator there read Continental Morse code signals at the rate of 15 words per minute, and in a further test of several minutes, at the rate of 25 words per minute with the greatest ease.

Excellent signals, both with 3 and 4 stages of amplification, were received at 100 cycles, and sending in Continental Morse code was easily read at a rate of 25 words per minute.

At 125 cycles the signals were distinctly audible with 4 stages of amplification, but too much interference from power sources was present to permit of clear reading. The power interference was of the same character as that observed at Juneau, and since the cables were interconnected through the office there, it is thought that the interference originated in the Juneau office and exposed cable. The attenuation of these interfering currents over the distance of 70 km. between Juneau and Haines would not be sufficient to make them negligible, because the incoming signals are attenuated in the same way.

Signals at 150 cycles were not readable on account of the interference.

AT SKAGWAY (686.4 km.).

Excellent signals at 50 cycles per second were received using 4 stages of amplifier. Whereas it had previously been somewhat doubtful if frequencies as low as 50 cycles per second would produce satisfactory telegraphic signals, the actual tests both here and at Haines showed that for a signaling rate as high as 25 words per minute, at least, this frequency serves as well as frequencies in the more sensitive region of audibility.

At 75 cycles the signals would have been perfectly satisfactory except for the interference from power circuits.

In the same way, 100-cycle signals were clearly audible with 4 stages of amplifier, but on account of the interference were not readable.

> The signals were just audible at 150 cycles, and at 200 cycles nothing at all could be heard.
>
> At Skagway, the cable comes in the sheath directly from the shore to the office through a trench of approximately 0.5 km. in length, passing near to power lines and transformers in the vicinity of the office.
>
> Disturbances created at this point undoubtedly affected both the tests here as well as at Haines, in addition to disturbances arising at Juneau.

The data contained in the above notes serve to establish the limiting values of voltage shown in Table XVIII.

The results of the trials as described above, and particularly when considered in conjunction with the mathematical analysis and calculations given are such as to fully justify the statement that a very great increase is possible in the usefulness of a great majority of existing cable systems. Although it is something that had not been hoped for, the calculations nevertheless show that this method of signaling is applicable even to an Atlantic cable. If it should prove capable of superposing even one message on the existing duplex working of an Atlantic cable, the method would increase the working value of such a cable by 50 per cent. On cables shorter than this, of which there are very many, the increase in working effectiveness would be still greater, because of the greater range in frequencies which can be utilized.

ACKNOWLEDGMENTS.

In conclusion it is desired to render acknowledgment to a number of people through whose effective aid the work described in the foregoing was made possible.

First, to the Chief Signal Officer of the Army, Major-General George O. Squier, must be given the credit for recognizing that work of the kind described was desirable, and even necessary, and for authorizing the Signal Corps Research Laboratory to proceed with the experimental work.

In addition to the writer, the experimental party consisted of

Dr. Sylvan J. Crooker, Radio Engineer,
Mr. Lester J. Rich, Radio Laboratory Assistant,
Mr. Chance E. Bohner, M.S.E., U. S. A.,

and for a portion of the time,

Mr. George L. Greves, Assistant Professor of Electrical Engineering, University of California.

Needless to say, to them is due the credit for the expeditious accomplishment of the work undertaken.

Without the active interest and coöperation of Lieut.-Col. B. O. Lenoir, Officer-in-charge, Washington-Alaska Military Cable and Telegraph System, the work could not have been carried out. Although every effort was made not to interfere with the regular operation of the system, the experimental work could not but cause considerable inconvenience. Much of the burden of keeping this disturbance at a minimum naturally fell on the chief operators, John A. Perry, M.S.E., at Seattle, and Phil McQuillan, M.S.E., at Sitka. Their efforts are very much appreciated.

For the trials of alternating-current transmission in southeastern Alaska, the Forest Service very kindly placed their gasoline cruiser, " Ranger V.," at the disposal of the testing party, and at the same time authorized the Forester at Sitka, Mr. Geo. A. Peterson, to accompany the expedition. Mr. Peterson's inimitable qualities as a host made the two weeks spent aboard his vessel, going from place to place in the waters of southeastern Alaska, a delightful experience long to be remembered.

Phosphorus in Butter.—According to J. T. Cusick (*Cornell University Agricultural Experiment Station Memoir 30*, pp. 153–187, 1920), approximately one-fourth of the total phosphorus of the cream is retained by the butter; the remaining three-fourths are lost in the buttermilk during churning, in the wash waters, and in the exudates which form during the process of salting. During storage, the organic phosphorus compounds are broken down into inorganic phosphorus compounds. The treatment of the milk and cream prior to churning influence the amount and the form of the phosphorus retained in the butter, and also determine how soon after storage the organic phosphorus compounds are transformed into inorganic compounds. Under certain conditions, bacteria are the controlling factors in producing chemical changes in the phosphorus compounds. Fishy flavor in butter is due to the decomposition of lecithin and the formation of trimethylamine ; development of this flavor is always accompanied by an appreciable decrease in soluble organic phosphorus. Salt in butter has a marked effect in bringing about decomposition of the proteins during storage, even at a temperature of −10° C. The recently discovered, alcohol-soluble protein of milk also occurs in butter.

J. S. H.

Finger-prints as Evidence.—The Navy Department, Bureau of Navigation, has recently issued a bulletin giving summaries of a considerable number of cases in which courts have sustained the use of finger-prints in criminal trials. The pamphlet was compiled by J. H. Taylor, finger-print expert of the Identification Division of the Navy, the method being extensively applied in that service for the identification of deserters. Foreign as well as domestic cases are cited, the first case given being from India in 1905 (Emperor vs. Abdul Hamid), the charge being false personation. Reports are printed from several police headquarters in different parts of the United States, which show that police authorities regard the method as of great certainty and satisfactory application, when well-trained experts are employed. The following report taken from a number submitted by the Chief of Police of San Francisco—in which office both the finger-print and Bertillon systems are employed—will serve to show the practical value of the method.

July 11, 1916, Robert Roubles was arrested on charge of burglary. Finger-prints were found on a window at a private residence, and the prisoner was identified as the one who had committed the crime. His record was found in the police department under the name of Wesley Baldwin.

The method has undoubtedly great value, but unfortunately the criminal classes have largely resorted to wearing gloves and in this way eliminating the traces of the prints.   H. L.

North America Third in Mountain Heights. (*U. S. Geol. Surv. Press Bull. No. 452, July-August, 1920.*)—North America ranks third among the continents in the heights of mountains. Asia has Mount Everest, of the Himalayas, which stands 29,002 feet above sea level, and South America has Mount Aconcagua, of the Andean system, which is 23,080 feet high. North America comes next with Mount McKinley, in Alaska, 20,300 feet, and Africa is fourth, with Kibo Peak, 19,320 feet. Mont Blanc, Europe's highest mountain, is 15,782 feet high, which is more than a thousand feet higher than any mountain in the United States outside of Alaska.

Cable Construction. (*Scientific American, August 7, 1920, p. 121.*)—Despite the great development of wireless telegraphy, submarine cables are still being constructed, and with the great increase in commercial and journalistic messages are still regarded as a necessary alternative to wireless, and by no means obsolete or likely to fall into disuse. In fact, a new cable to the Far East from Great Britain through the Mediterranean, involving a length of 7000 miles, is being laid section by section as ready, while the possibility of a new cable from Vancouver to Fanning Island is now being discussed.

INDUSTRIAL ALCOHOL.*

BY

BURNELL R. TUNISON.

U. S. Industrial Alcohol Company, New York City.

To the layman, the word alcohol merely signifies that con-
stituent (ethyl alcohol, grain alcohol, ethanol) which imparts
intoxicating properties to spirituous, vinuous, and malt beverages.
He incorrectly defines industrial alcohol as the relatively small
amount of alcohol which is used in pharmacy, in the compounding
of drugs and the manufacture of various pharmaceutical prepara-
tions. As a matter of fact, according to the United States Bureau
of Internal Revenue, it is estimated that almost 52,490,000 proof
gallons of alcohol were used during the year 1918 exclusively for
the manufacture of explosives and other war purposes. Since
ethyl alcohol is commonly called grain alcohol, most people con-
sider that it is made from grain, and that its manufacture further
increases the world food shortage. In order to correct these very
prevalent misconceptions as to alcohol for industrial purposes,
an attempt will be made to explain some of the more important
phases of industrial alcohol.

HISTORICAL.

While the history of industrial alcohol probably dates from
the beginning of the development of industrial chemistry, this
product has been of importance in the United States for only a
few years. In nearly every country alcohol had been known for
centuries as a component of many of the popular beverages
before it became an article of industrial importance. Most
nations had experienced the results of alcoholism and had levied
taxes on alcoholic beverages for the purposes of obtaining
revenue and to curb to some extent the indiscriminate use
of such beverages.

Probably the first recognition of alcohol as such was by the
alchemist Basilius Valentinus, who recognized in spirit of wine
the chief product of fermentation. In 1689 the German physician
and chemist Becker thought that fermentation was a process

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* Communicated by the Author.

similar to combustion, on account of the similarity of the waste gases evolved. He also stated that only the different varieties of sugars were capable of alcoholic fermentation.

Although, little by little, knowledge was acquired concerning alcohol and alcoholic fermentation, it was not until the studies of Pasteur that any marked progress was made. This investigator carefully studied the specific properties of the yeasts and the nourishment, growth, and multiplication of their cells.

On account of the microscopic size of the yeast cells, definite knowledge concerning them was not obtained until the development of the modern microscope. Although early investigators had seen yeast cells, it was not until the microscope reached a high state of perfection that the organisms were systematically studied.

Traube, in 1858, explained that fermentation was due, not to the yeast cell itself, but to certain substances which were produced or secreted by these cells; however, this theory was discredited for many years. One of the many theories explaining alcohol formation was that sugar was taken in as food by the yeast, and alcohol and carbon dioxide were given off. Liebig held that sugar was mechanically decomposed as a result of the molecular motion, and that the yeasts themselves were a product of the reaction and not its cause.

Not until recent years was the theory set forth by Traube shown to be essentially correct. It is now believed that fermentation processes are due only indirectly to the cells themselves, and directly to enzyme action. These enzymes are formed by living yeast cells and act on the invert sugars in such a manner as to split them into alcohol and carbon dioxide.

Although Germany probably was the first to recognize the industrial value of alcohol, Great Britain was the first country which attempted to denature or methylate ordinary alcohol. For a number of years Great Britain had levied a tax on alcohol; and, in 1855, the use of methylated spirit for industrial purposes was authorized. This methylated spirit was exempted from the taxes which had been imposed on alcohol. The methylated or denatured alcohol was made by mixing 10 per cent. of commercial methyl or wood alcohol with ethyl alcohol. The methyl alcohol used for denaturing was a product which contained a certain

portion of acetone and other components which were difficult of separation.

In 1865 the Netherlands authorized the use of denatured alcohol for manufacturing purposes. A law giving greater freedom was enacted in 1872. The use of such methylated spirits, and the use of spirits for special purposes was subject to regulation by the Government.

France has permitted the use of denatured alcohol under a modified tax since 1872. The law was modified in 1881, with respect to the quality of the denaturant. In addition to the methyl alcohol, some heavy benzine and green dye were used. Other denaturants have since been authorized.

The use of tax-free alcohol for industrial purposes has been permitted in Germany since 1879. Several laws have been enacted since that time giving greater freedom of use, and adding additional formulæ for denaturing. Germany has authorized the use of many denatured alcohols and has stimulated the use of such alcohol by subsidy, etc., so that alcohol for manufacturing purposes is cheaper in Germany than in any other country. Undoubtedly this fact has had a tremendous influence on the development of the German chemical industries.

After some of the larger countries had enacted laws for the use of tax-free alcohol for manufacturing purposes, other countries were not slow in following their example. The use of tax-free alcohol for industrial purposes was authorized by:

Austria ....in 1888
Italy ....in 1889
Sweden ....in 1890
Norway ....in 1891
Switzerland ....in 1893
Belgium ....in 1896

The history of the taxation of alcohol in this country may be briefly summarized. On account of the need of revenue in the early days of the country, a tax on distilled spirits was imposed in 1791. Thomas Jefferson caused a repeal of this law in 1802. The expenses of carrying on the war with Great Britain led to the levying of a tax on spirits in 1813. This law was repealed in 1817; and no other tax was imposed until the time of the Civil War when a tax of 20 cents per gallon was levied. In 1868 this was increased to 50 cents; in 1872 to 70 cents; in 1875

to 90 cents; in 1894 to $1.10 per gallon, and that rate continued until 1917, when the tax was increased to $3.20 per proof gallon for beverage spirits and $2.20 for non-beverage variety.

Thus 95 per cent. undenatured alcohol for manufacturing purposes is taxed at the present time at the rate of $4.18 per gallon.

Limited exemptions have been provided at various times when taxes were levied. For instance, a law of 1878 authorized the Secretary of the Treasury to permit " any incorporated or chartered scientific institution or college of learning to withdraw alcohol in specified quantities from bond without payment of the Internal Revenue tax on the same, or on the spirit from which the alcohol has been distilled, for the sole purpose of preserving specimens of anatomy, physiology, or natural history belonging to such institution, or for use in its chemical laboratories." To this was attached a proviso that the application for a permit must be made by the President or Curator of the Institution and they were required to file a bond for double the amount of the tax on the alcohol to be withdrawn, with two good and sufficient securities.

In 1897 a careful and comprehensive investigation in this country and abroad of the question of tax-free alcohol for industrial purposes did not result in the passage of the bill under consideration. The investigation was continued and brought to an issue which resulted in the passage of the Denatured Alcohol Act of 1906. This law provided in part (Regulations 30—Revised—page 1) : " From and after January first, nineteen hundred and seven, domestic alcohol of such degree of proof as may be prescribed by the Commissioner of Internal Revenue, and approved by the Secretary of the Treasury, may be withdrawn from bond without the payment of internal-revenue tax, for use in the arts and industries, and for fuel, light, and power, provided said alcohol shall have been mixed in the presence and under the direction of an authorized Government officer, after withdrawal from the distillery warehouse, with methyl alcohol or other denaturing material or materials, or admixtures of the same, suitable to the use for which the alcohol is withdrawn, but which destroys its character as a beverage and renders it unfit for liquid medicinal purposes; such denaturing to be done upon the application of any registered distillery in denaturing bonded

warehouses specially designated or set apart for denaturing purposes only, and under conditions prescribed by the Commissioner of Internal Revenue with the approval of the Secretary of the Treasury.

" The character and quantity of the said denaturing material and the conditions upon which said alcohol may be withdrawn free of tax, shall be prescribed by the Commissioner of Internal Revenue who shall, with the approval of the Secretary of the Treasury, make all necessary regulations for carrying into effect the provisions of this act.

" Distillers, manufacturers, dealers and all other persons furnishing, handling, or using alcohol withdrawn from bond under the provisions of this act, shall keep such books and records, execute such bonds and render such returns as the Commissioner of Internal Revenue, with the approval of the Secretary of the Treasury, may by regulation require.   Such books and records shall be open at all times to the inspection of any internal-revenue officer or agent."

The National Prohibition Act recently passed had a double purpose as indicated by Congress in naming the Act after due deliberation as follows :

" An Act to prohibit intoxicating beverages, and to regulate the manufacture, production, use, and sale of high-proof spirits for other than beverage purposes and to insure an ample supply of alcohol and promote its use in scientific research, and in the development of fuel, dye, and other lawful industries."

It will be noted that one of the purposes of the Act is *to insure an ample supply of alcohol and promote its use in the lawful industries.*

This Act provides that undenatured ethyl alcohol may be withdrawn free of tax by the following :

" The United States or any Governmental Agency thereof, or by the several States and Territories or any municipal subdivision thereof, or by the District of Columbia, or for the use of any Scientific University or of College of Learning, any laboratory for use exclusively in scientific research, or for use in any Hospital or Sanatorium."

Notice should be taken that *any laboratory may obtain pure ethyl alcohol tax-free for use exclusively in scientific research.*

Alcohol may also be withdrawn tax-free for denaturation in accordance with regulations No. 61, which provide:

" Upon the filing of application and bond and issuance of permit denaturing plants may be established upon the premises of any industrial alcohol plant, or elsewhere, and shall be used exclusively for the denaturation of alcohol by the admixture of such denaturing materials as shall render the alcohol or any compound in which it is authorized to be used unfit for use as an intoxicating beverage.

" Alcohol lawfully denatured may, under regulations, be sold free of tax either for domestic use or for export."

Nearly fifty formulæ have been authorized which are exempt from tax when used for industrial purposes under U. S. Internal Revenue permit and bond. Five separate formulæ of completely denatured alcohol have been authorized, which alcohol may be used by manufacturers or the general public without permit or bond, and which alcohol is not subject to tax or regulation by the Internal Revenue Bureau.

MANUFACTURE OF ALCOHOL.

Raw Materials.

In the manufacture of alcohol for industrial purposes a great variety of raw materials may be used. Alcohol is made by the fermentation of sugars, but the only sugars which are directly fermentable into alcohol and carbon dioxide are the sugars having the composition $C_6H_{12}O_6$, or the monosaccharoses, such as dextrose and levulose. All other sugars, such as cane sugar $C_{12}H_{22}O_{11}$, or the disaccharoses, are not directly fermentable, but by action of certain enzymes (*e.g.*, *invertase*) they are converted into fermentable sugars; and then an enzyme of the yeast (zymase) brings about alcoholic fermentation.

Alcohol may also be made from more complex compounds. Starch, dextrin, and cellulose are all highly complex substances, the molecules of which seem to consist of combinations of the molecules of the mono- or di-saccharoses, with loss of the elements of water; they are therefore called the poly-saccharoses.

These poly-saccharoses, when hydrolyzed, form fermentable sugars. Assuming the formula for starch, for example, as being $(C_6H_{10}O_5)n$ the reaction is as follows:

$$(C_6H_{10}O_5)n + nH_2O \longrightarrow n(C_6H_{12}O_6)$$
$$162 \quad\quad 18 \quad\quad\quad\quad 180$$
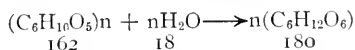
Thus, the starch will take up one-ninth of its weight of water, or nine pounds of starch will form 10 pounds of fermentable sugar.

$$C_6H_{12}O_6 \longrightarrow 2CO_2 + 2C_2H_5OH$$
$$180 \quad\quad\quad 88 \quad\quad\quad 92$$

$$\frac{180}{92} = \frac{10}{x} = 5.111$$
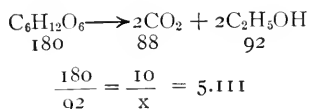
This reaction would give theoretically a little more than five pounds of absolute alcohol from 9 pounds of starch or 10 pounds of fermentable sugar, or a theoretical yield from starch of 56.78 per cent. alcohol by weight. In practice, when making alcohol for industrial purposes, where no attention is paid to flavor, etc., a yield of over 90 per cent. of the theoretical is obtained.

The raw materials which may be used for the production of industrial alcohol may be more or less arbitrarily classified as follows:

Grains and Kernels:

Wheat
Barley
Oats
Rye
Millet
Rice
Buckwheat
Corn
Maize
Ragi

Roots:

Sugar beets
Potatoes
Artichoke (Jerusalem)
Cassava
Sweet potatoes
Carrots
Turnips
Mangolds

Fruits and Berries:

Apple
Apricot
Banana
Orange
Grape
Peach
Plum
Pear
Cherries
Melons
Pineapple
Prickly pear
Watermelon
Figs
Raspberries
Huckleberries
Blackberries
Gooseberries
Currants
Prunes

Strawberries
Dates
Mulberries

Stems and Leaves:

Agave
Cactus
Sorghum
Stalks of sugar corn
Sugar cane
Zamia palm (*Macrozamia*)
Grasstree (*Xanthorrœa*)
Nipa palm
Sotol
Seaweed
Date palm

Mahua (*Bassia Satifolia*)
Cocoanut palm
Sago palm
Other trees
Bracken and other vegetation

Trade Wastes

Corn cannery refuse
Sulphite liquor
Garbage
Sawdust
Cane molasses
Beet molasses
Fruit
Gases from coal carbonizing plants

In addition to the above may be mentioned peat, horse-chestnuts and acorns.

At various times, in the different countries, practically all grains have been used for the production of alcohol. The yields obtained differed widely, due to the method of handling, also to the particular grain and its composition. McIntosh ("Industrial Alcohol," p. 62) gives the average composition of grains and cereals as follows:

	Old wheat	Barley	Oats	Rye	Maize	Rice
Water	11.1	12.0	14.2	14.3	11.5	10.8
Starch	62.3	52.7	56.1	54.9	54.8	78.8
Fat	1.2	2.6	4.6	2.0	4.7	0.1
Cellulose	8.3	11.5	1.0	6.4	14.9	0.2
Gum and sugar	3.8	4.2	5.7	11.3	2.9	1.6
Albumenoids	10.9	13.2	16.0	8.8	8.9	7.2
Ash	1.6	2.8	2.2	1.8	1.6	0.9
Loss	0.8	1.0	0.2	0.5	0.7	0.4
Total	100.0	100.0	100.0	100.0	100.0	100.0

McIntosh ("Industrial Alcohol," p. 65) also says that the yield of alcohol from the grains is:

Alcohol sp. gr. 0.9427. 9/11
British proof spirit, in lbs.

100 pounds wheat 40–45
100 pounds rye 36–42
100 pounds barley 40
100 pounds oats 36
100 pounds buckwheat 40
100 pounds maize 40

Wright states (" Distillation of Alcohol," p. 126) that the yields of alcohol from grains are:

220 pounds wheat ....give 7.0 gallons pure alcohol.
220 pounds rye ....give 6.16 gallons pure alcohol.
220 pounds barley ....give 5.5 gallons pure alcohol.
220 pounds oats ....give 4.8 gallons pure alcohol.
220 pounds buckwheat ......give 5.5 gallons pure alcohol.
220 pounds corn (Indian) ...give 5.5 gallons pure alcohol.
220 pounds rice ....give 7.7 gallons pure alcohol.

Corn has been used in nearly all countries for the production of alcohol. The average corn should give theoretically 20.7 pounds of absolute alcohol per bushel. The yield actually obtained is about 16 to 18 pounds per bushel. On account of the high price of the corn suitable for food purposes, only the lower grades of this material are used.

Maize has been a very important source of alcohol in this country for many years. Dry corn of good quality should contain at least 65 per cent. of sugars and starch, and should yield from 98 to 105 gallons of 180° proof alcohol per ton of shelled kernels.

Sugar Beets.—The average sugar content of the varieties of beets used for alcohol production varies between 12 and 20 per cent. Beets have not been used directly to any extent for alcohol production in this country. In France they have been used to a considerable extent. The data obtained from distillery yields in France show that, from every 220 pounds of sugar contained in the beets entering the distilleries, 15.64 gallons of alcohol of 100 per cent. strength were produced, equivalent to 17.4 gallons at 180° proof.

Beet Molasses.—A refuse from the manufacture of beet sugar is used in large quantities abroad as a raw material for the production of alcohol. It usually contains nearly 50 per cent. sucrose, with only traces of reducing sugars, and generally needs only to be diluted to prepare it for fermentation. One ton should yield between 75 and 80 gallons of alcohol of 180° proof.

Potatoes.—In the European countries potatoes have been used very extensively for the production of industrial alcohol. Most of the industrial alcohol made in Germany is derived from a potato grown chiefly for this purpose. In Germany the yield of alcohol is about 26 gallons absolute alcohol per ton of potatoes. This yield is approximately 80 per cent. of the theoretical, based on the starch content of the potatoes. With an average starch

content of 18 per cent. they should yield about 30 gallons per ton. In some localities sweet potatoes have been used very successfully for the production of alcohol, but not to such an extent as the potato which is grown in Germany for use in the manufacture of alcohol.

The sweet potatoes used for alcohol manufacture contain a considerably larger amount of fermentable matter than the common potato, much of it in the form of sugar; but on account of their irregular form and the difficulty of removing the culls except by hand labor, they would probably be a more expensive material. With a content of 28.8 per cent. fermentable substances, a ton should produce about 38 gallons of alcohol.

Artichoke.—The tubers of the artichoke contain, on an average, about 14 per cent. of directly fermentable levulose and about 2 per cent. of starch which can be converted into sugar.

Sorghum.—This plant contains from 6 to 15 per cent. of levulose and crystallizable sugar. It may become a source of industrial alcohol.

Sorghum deserves considerable attention because of the readiness with which it is grown, the extent of the territory in which it flourishes, and the large amount of sugar which certain varieties contain.

Fruits and Fruit Wastes.—Fruits and fruit wastes may be used for the production of alcohol, but in most cases the fruits are too valuable to use for such purposes, and the wastes do not occur in sufficient quantities to be available at a distillery. Transportation of these wastes is of course not feasible. The possible yields of alcohol from the various kinds of fruits are given by Wiley (U. S. Department of Agriculture, Bureau of Chemistry Bulletin No. 130 (1910), page 29):

Kind of fruit	Average percentage of total sugars, calculated as dextrose	Gallons of 180° alcohol yielded by total sugars contained in one ton of material
Apple	12.2	18.3
Banana	13.8	20.7
Grape	15.0	22.6
Orange	5.4	8.1
Peach	7.6	11.4
Pear	10.0	15.0
Pineapple	11.7	17.6
Prickly pear	4.2	6.3
Tomato	2.0	3.0
Watermelon	2.5	3.7

While many different *berries* have been used in the making of alcoholic beverages, in most cases they cannot be used economically for the production of industrial alcohol.

Another author (*Scientific Australian*, 1918, p. 968) states that the approximate yield of alcohol obtainable from various sources is:

Material	Imperial gallons of alcohol (95 per cent.) per ton of 2,240 lbs.
Sugar molasses	65
Sorghum stalks	12–½
Wheat	83
Barley	70
Maize	85
Sorghum grains	87
Potatoes	20
Sweet potatoes	35
Sugar beet	18
Artichokes	22
Cassava	39
Apples and pears	12
Apricots and peaches	11
Grapes	18
Bananas	13
Watermelons	3
Zamia palm (*Macrozamia*)	18
Grasstree (*Xanthorrœa*)	12
Sawdust (soft woods)	20

The *agave and cactus* have been used in Mexico and in the southwestern parts of the United States for the production of alcoholic beverages. It is possible that they may be used for the production of industrial alcohol, but as yet they are not so used commercially.

Stalks of Sugar Corn.—Stalks of sugar corn contain considerable amounts of sucrose and of reducing sugars, making this material valuable as a source of alcohol.

Sugar Cane.—Sugar cane under ordinary circumstances is too valuable to be used for industrial alcohol production, but at times, as when the cane has been heavily frosted, it may be used. The yield of alcohol from sugar cane averages between 15 and 20 gallons of alcohol 180° proof per ton of cane.

Nipa Palm.—Concerning the nipa palm as a raw material for industrial alcohol, the following statement has been made ("Pure Products," 1918, No. 14, p. 286): "There are over 100,000 acres of nipa swamp now available in the Archipelago

(Philippines) of which about 90 per cent have never been touched, and it is estimated that the untapped swamp area of the island would yield 50 million gallons of alcohol every season."

The most important raw materials for the production of industrial alcohol are the various trade wastes.

Corn Cannery Waste.—Corn cannery waste has been used to some extent in this country as a raw material for alcohol production. These wastes amount to about 40 per cent. of the total weight of corn brought to the factory, not counting the husks as available, although these amount to nearly one-third of the total weight of the corn. It is possible to obtain 10 to 11 gallons of 180° proof alcohol per ton of corn hauled to the factory, or about 27 gallons per ton of factory waste excluding husks.

Sulphite Liquors.—Fermentable sugars are found in small percentages in the waste liquors resulting from sulphite paper pulp manufacturing. A large number of processes have been tried and patented for the production of alcohol from sulphite waste. Although there are many attractive features to the manufacture of alcohol from sulphite liquor, there are many technical difficulties to be overcome. Even though these difficulties may be overcome, this source of alcohol will not be very great because there are very few localities where a sufficient amount of waste sulphite liquor could be collected to produce over 1500 to 2000 gallons per day. The overhead expense of operating plants with such small outputs is high, and the total amount produced would not be a factor in the market.

Sawdust.—A number of patents have been issued to various inventors to cover processes for the production of alcohol from sawdust. These patents cover the conditions of temperature and pressure of the hydrolysis, and the use of various acids which have been proposed to catalyze the reaction. In the Classen process, which was tried out at Chicago several years ago, the sawdust was cooked under pressure with live steam in the presence of sulphur dioxide as the hydrolyzing agent. This enterprise failed on account of poor yields. The Standard Alcohol Company built a plant at Fullerton, La., to operate under the Tomlinson patents; in this process either sulphuric acid or a mixture of sulphuric and sulphurous acids was used as a hydrolyzer. A later plant was built at Georgetown, South

Carolina, using the same process. F. W. Kressmann (" The Congressional Record," 1916) stated that the Forest Products Laboratory results indicated that the possible yield would be approximately 20 gallons of alcohol per ton of dry sawdust and that the cost would be :

Yeast nutrients: This item may go as high as $0.035 in some
    sections since the war; also rapidly advancing prices of
    iron, steel, and copper, particularly the latter, will require
    some increase in the estimate, which were figures for
    market conditions existing over a year ago ....$0.015–$0.020
Repairs and materials (exclusive of fuel and wood) .... .030– .040
Labor .... .015– .030
Wood and fuel .... .020– .020
Interest at 7 per cent. .... .019– .020
Depreciation at 10 per cent. .... .023– .035
Overhead, taxes, etc. .'............................... .015– .030

Total $0.137–-0.195

    " In the above table wood has been valued at $0.40 per cord of 1800 pounds of dry wood per cord. This should consist of sawdust and hogged refuse, but should not contain over 10 per cent. of bark, since the yield of sugars and alcohol from bark is very low. A large quantity of bark would mean running a large volume of inert material through the alcohol plant at considerable expense without return, and in the case of most barks would add large quantities of undesirable tannin to the solution to be fermented."

    At the present time there are two plants of relatively small capacity in operation in the United States, manufacuring alcohol from sawdust, one at Georgetown, South Carolina, and the other at Fullerton, Louisiana.

    Cane Molasses.—The chief source of industrial alcohol in the United States is cane, or black strap, molasses. Only a few years ago the disposal of molasses by the sugar mills was a serious trade waste problem, but it is now very largely used the world over as a raw material for alcohol manufacturing. In the East and West Indies molasses disposal was a matter of expense. The conversion of molasses into alcoholic liquor, especially into rum, is an old enterprise. West India rum has been famous in New England for more than 200 years. But the use of molasses in large quantities for industrial alcohol production is a development of the last few years. As far as ease of manipulation is

concerned, molasses unquestionably surpasses any other known material. Also in the past it has been a very cheap material. Ordinarily it contains both sucrose and reducing sugars in varying proportions. The grades used by distillers usually contain between 45 and 60 per cent. sugars, averaging about 50 per cent. The yield of alcohol from such molasses is from 0.6 to 0.85 proof gallons of alcohol per gallon of molasses. A large portion of the

FIG. 1.
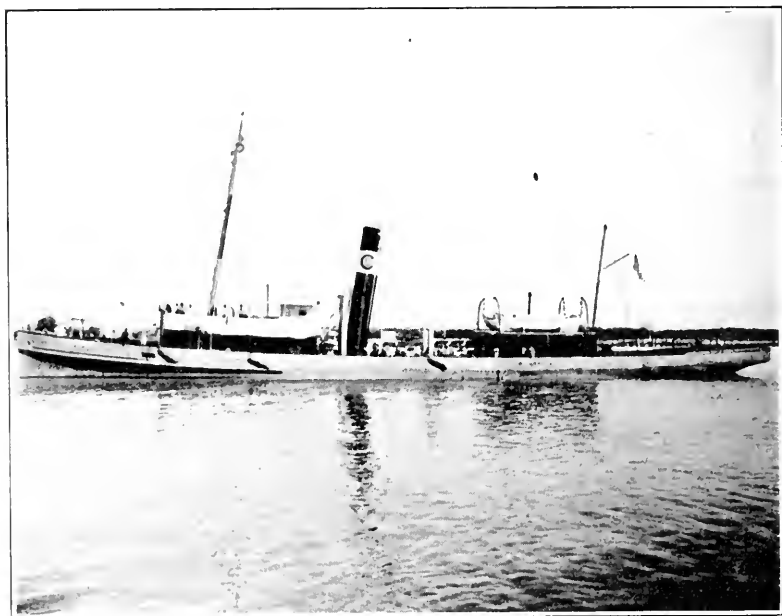
Molasses lighter, Cuba.

world's molasses is still a waste product due to the difficulty and expense of transportation to the commercial centres.

Molasses from Cuba and Porto Rico is of special importance to the United States, since several million tons are available annually for the production of alcohol. Many of the producing mills are located on waterways. From these mills the molasses is collected in light draught tank barges or lighters and transported to deep-water shipping points. From the other mills the molasses is taken in hundreds of tank cars and, in a few instances, in barrels or hogsheads. Large storage tanks are pro-

vided at the deep-water shipping ports for containing the molasses
until sufficient quantity has accumulated to load a tank steamer.
Tank steamers, such as are used for the transportation of petro-
leum, are used to carry the molasses from these storage points to
various plants in the United States: in Boston, Brooklyn, Balti-
more, New Orleans and other points.

  Calcium Carbide.—Another source of alcohol which may

FIG. 2.

Molasses cars, Cuba.

become important in localities where cheap power is available is
calcium carbide. It was stated by Consul W. P. Kent, of Berne,
Switzerland ("Commerce Reports," 1917, No. 102, p. 426), that
installations were started with about 20,000 horse-power mini-
mum and 30,000 horse-power maximum (summer time), which
would produce from 7500 to 10,000 tons of alcohol per annum.
Calcium carbide is produced by the usual electric furnace method,
and acetylene from the calcium carbide by the action of water.
Two methods are used in the production of alcohol from the
acetylene. (1) The acetylene is hydrogenated by catalytic means

Mr. Grady (" Commerce Reports," No. 21, p. 506 (1920)) in discussing the development of this process states:

> The extraction of alcohol from coke-oven gas on a commercial scale was proved to be possible at a meeting of the Cleveland Institution of Engineers at Middlesbrough (England) by Mr. E. Bury, of the Skinningrove Iron and Steel Works. Mr. Bury showed that he had succeeded in extracting ethyl alcohol and its derivatives. The practical working of Mr. Bury's process at the Skinningrove plant, where 5800 tons of coal are carbonized per week, revealed an average yield of 1.6 gallons of alcohol per ton of coal carbonized.

FIG. 4.
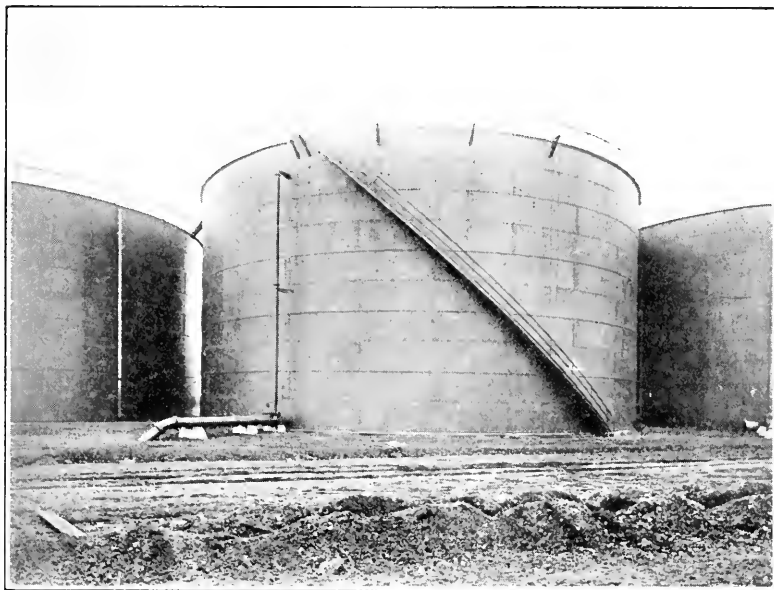
Molasses storage, United States; capacity of each tank, 1,500,000 to 2,000,000 gallons.

Straw.—Recently Henry Ford (*Oil and Gas Journal,* 18, 36) has been quoted as follows:

> I am now making the best fuel my tractors can use out of straw. I have got an inexhaustible supply of fuel on my farm and believe the day is coming when we will extract the alcohol out of fruit for fuel and use the rest for food. I am putting up a $35,000 plant now to manufacture alcohol from straw alone; just to show people that it can be done.

This process is still of an experimental nature and has no commercial significance at present.

Preparation of Raw Materials.

As the saccharine raw materials contain their fermentable matter in the form of diffusible sugars which are already in solution, they require relatively little preliminary treatment to fit them for fermentation. Materials like sugar beets and fruits are best prepared by rasping or grinding and pressing. Fibrous materials, like sorghum and cane, may be pressed in roller mills or they may be sliced and extracted in diffusion batteries. Sugar beets can also be extracted by diffusion.

Beet molasses, cane molasses, and other saccharine materials when in liquid form, are diluted with water, and acidified, and are then ready for the alcoholic fermentation.

As already indicated, starchy or cellulose materials do not themselves undergo alcoholic fermentation, but must first be converted into a fermentable sugar. " Mashing " is the term used to designate the series of processes by which starchy raw materials are prepared for yeast production or fermentation by means of heat and of enzyme action. The starchy material is first ground and heated with water to gelatinize the starch. This forms the " mash " which is then saccharified by means of malt (some grain, usually barley, in which the production of the enzyme diastase has taken place), the conversion of starch into sugar being effected through the action of the enzyme diastase (amylase). The resulting liquid is known as the " wort " and is essentially a solution of sugar with dextrin and other components obtained from the starchy material.

These processes of mashing and saccharification result in the formation of soluble and fermentable sugar, and incidentally in the development of certain nitrogeneous substances which are necessary to yeast activity.

Fermentation.

After the material has been prepared ready for fermentation it is brought to a proper temperature and the yeast added. The yeast which is a vegetable mono-cellular organism, under the conditions prevailing in distillery practice, reproduces itself by budding and sprouting. Yeast reproduces very rapidly and most distilleries start with biologically pure cultures and develop them until a sufficient number have been grown to start fermentation in the large fermenters. There are usually several

stages to the growth of sufficient yeast and several changes to
larger containers as the growth takes place.

After the addition of yeast to the liquid to be fermented for
alcohol, fermentation proceeds and the alcoholic mixture or
" mash " is produced. The alcohol is obtained from the mash
by distillation and rectification.

It has been found that certain moulds secrete the amylase
(diastase) and also fermentation enzymes. This property has
been utilized in a process which combines saccharification and

FIG. 5.
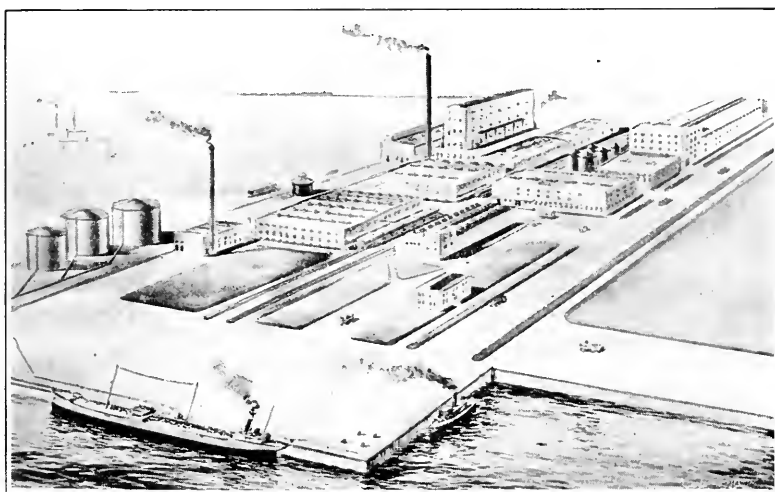
Modern industrial alcohol plant.

fermentation, whereby the use of malt is dispensed with in
obtaining alcohol from starchy materials. This method has been
employed on a large scale in Belgium, France, Hungary, Spain,
Italy, and Germany. This so-called " Amylo " process originally
employed the mucor *Amylomyces Rouxii* from which the process
was named. This organism was later on supplanted by other
moulds. This process has many other advantages over the older
process and its development has been very rapid and far-reaching
in its effect.

Distillation.

Theoretically the alcoholic fermentation of sugars should
give carbon dioxide and ethyl alcohol, but the decomposition is

not as smooth a process as this, for there are always formed a number of by-products which decrease the amount of alcohol recovered. Yeast is an organism which consumes sugar for its nourishment and propagation, and also converts sugar into other substances besides alcohol and carbon dioxide during its metabolic changes, thus reducing the percentage conversion. The products other than alcohol formed in the fermentation are usually glycerol, succinic acid, lactic acid, butyric acid, acetic acid, pro-

FIG. 6.

Alcohol stills, capacity, 60,000 gallons each.

pionic acid, formic acid, aldehydes, higher alcohols, and ketones, with sometimes small quantities of various esters (ethyl acetate, butyrate, caproate, etc.). In order to separate the alcohol from these products as well as the yeast cells, water, etc., a distillation is made.

Upon completion of the fermentation, the fermented liquors are transferred to a still in order that the alcohol may be removed from the mass. In the United States the development of the stills used for this purpose has been very interesting. The early settlers along the eastern coast, when they started to make their alcohol, had to rely on the use of a copper kettle still which

was boiled over an open fire; and the resulting vapors were condensed in a cooled coil. When the charge was distilled out, the kettle was cleaned, and the distillate obtained was charged into the still and redistilled. This process of redistillation was repeated until alcohol of the desired strength was obtained. The next improvement was the introduction of a steam boiler and the heating of the still by means of steam. It was found that

FIG. 7.
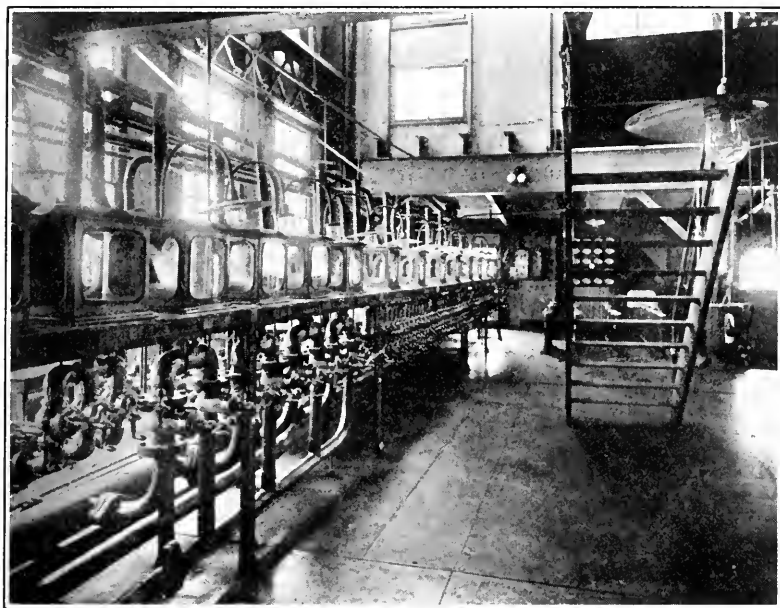
Tail boxes flowing 60,000 gallons of pure alcohol per day.

even a number of distillations would not give an alcohol of suitable strength, so the idea was conceived to return to the still all but the desirable fraction. This resulted in the still with a simple dephlegmator which allowed the condensed liquid to return to the still. In time this was modified so that a dephlegmating column was introduced. At present there are innumerable schemes to enable better separation of the components, a number of them designed in such a way that they may be run continuously.

Usually the alcohol is separated from the fermented mass by a primary distillation. This distillation separates the alco-

holic liquors from the yeast, water and most of the other impuri-
ties of the fermentation. This alcohol still contains too high a
percentage of aldehydes, water and higher boiling components
(fusel oil) to be used commercially; so it then undergoes a
secondary separation or rectification.

Rectification.

The purpose of this fractional distillation is to cause a sepa-
ration of the alcohol from the water, aldehyde, and fusel oil

FIG. 8.
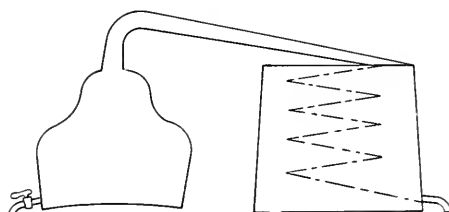
Simplest form of pot still.

FIG. 9.
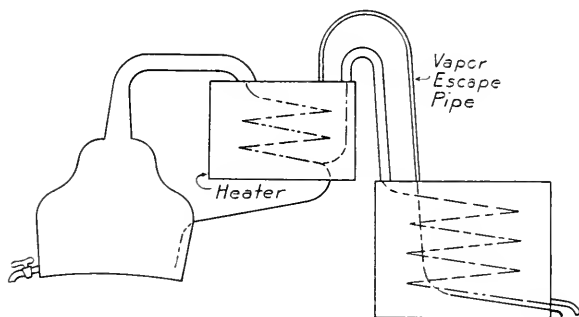
Pot still with heater.

with which it is associated when obtained by the first distillation.

The apparatus used for this purpose usually consists of a
kettle still which is connected to the bottom of the rectifying
column. This column consists of a vertical cylindrical shell,
which is divided horizontally into a number of sections by plate
partitions. These plates are constructed so that a volume of liquid
is held at a certain level before it is allowed to overflow to a next
plate below. The ascending vapors are made to bubble through
the liquid held on the plates. Thus the column is a series of

FIG. 11.

Condenser

Tail Box

Tank

Cold Water

Water Overflow

Cold Crude to Heater

Crude Heater

Hot Crude to Still

Chambers Omitted

Slop Outlet

Still

Steam
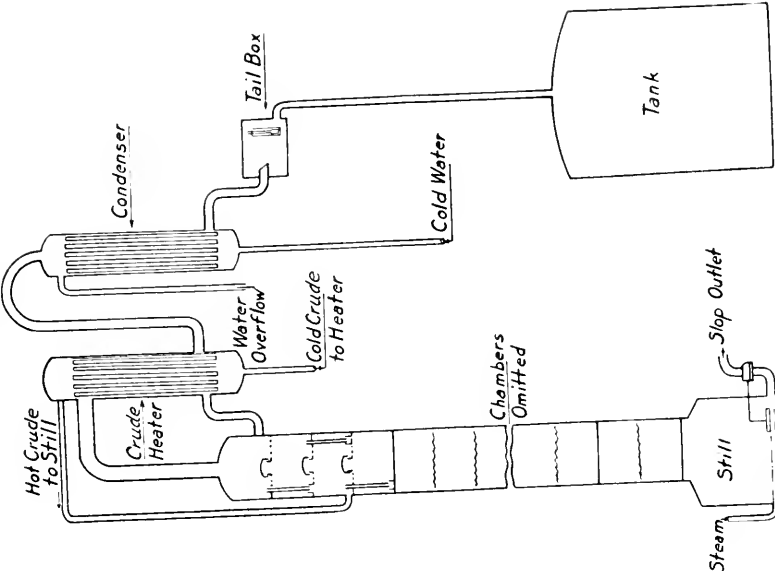
Simple crude alcohol still.

FIG. 10.

Water Overflow

Condenser

Tail Box

Cold Water

Cistern

Chambers Omitted
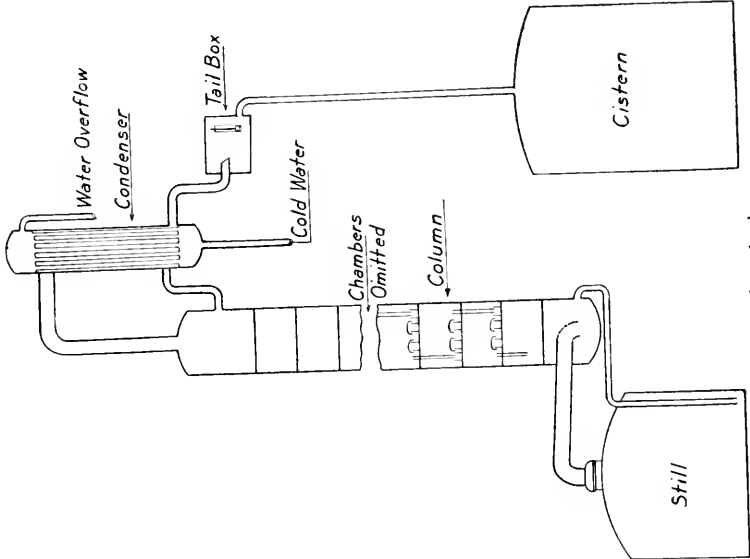
Column

Still

Simple kettle and column.

small stills, each plate having a little lower boiling fraction than
the next plate below it.   The continued washing of the ascending
vapors by the liquid condensed on the plates, and the bubbling
of the vapors through the liquid, causes a very complete separa-
ration of the components.   On the top of the column the usual
practice is to pass the vapors from the top plate through a
dephlegmator which causes the final separation.   The run back
from the dephlegmator is either placed in the top of the column
or between two of the top plates.   The vapors from the top of the

Fig. 12.
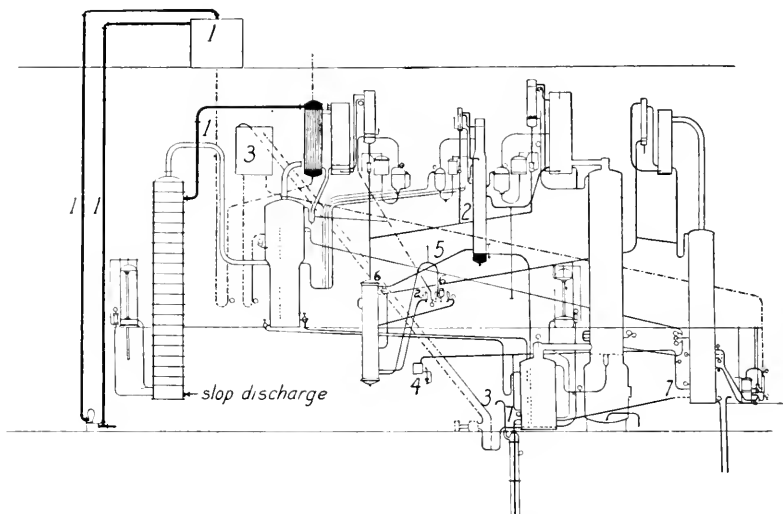
GUILLAUME SYSTEM DIRECT DISTILLATION AND RECTIFICATION.
1, Crude alcholic liquor; 2, aldehydes; 3, warm water; 4, fusel oil; 5, cold water; 6, alcohol;
7, steam.

dephlegmator are passed through a condenser where they are
liquified.   By means of such an apparatus it is possible to hold the
composition of the alcohol out from the condenser to 188 to
194° proof, or 94 to 97 per cent. alcohol.

As the uses for the higher grades of alcohol developed, the
demand caused more careful attention to be paid to the details
of rectification.   In France and Germany the progress in this
respect was especially marked.   Continuous methods of distilla-
tion and rectification were worked out, such as the Barbet and the
Guillaume rectification systems.   That these must be complex can
be realized when we consider that the object is to separate alcohol

from the several component mixture composed of water, alde-
hydes, higher alcohols or fusel oil, acids and fermentation im-
purities. Alcohol forms mixtures with water which distill at a
constant temperature when the pressure is kept constant, without

FIG. 13.
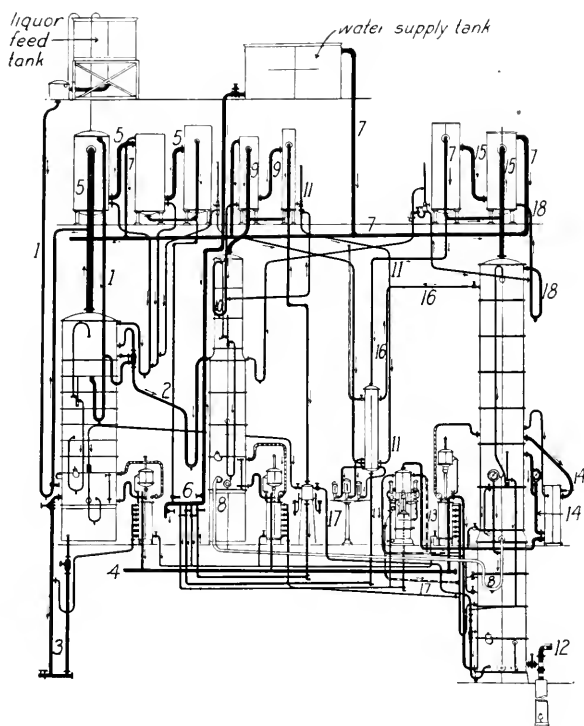
BARBET SYSTEM CONTINUOUS DISTILLATION AND RECTIFICATION.

1, Crude alcoholic liquor; 2, high wine, crude; 3, slop from distilling column; 4, steam piping;
5, alcohol vapor, distilling column; 6, water supply piping; 7, hot water piping; 8, high wines
purified; 9, alcoholic vapor, heads concentrating column; 10, condensed alcoholic liquid from
dephlegmator heads concentrating column; 11, condensed head products; 12, slop from rectify-
ing and exhausting column; 13, fusel oil removal pipes, rectifying and exhausting column;
14, liquid connecting pipes to special cooler; 15, alcoholic vapor, rectifying and exhausting
column; 16, refined alcohol; 17, head products from rectifying and exhausting column; 18, con-
densed alcoholic liquid from dephlegmator, rectifying and exhausting column.

change of composition. At 760 mm. pressure the mixture of
constant boiling-point distills at 78.15° C. and contains 4.43 per
cent. of water by weight (Young, *Trans. Chem. Soc.*, **81**, 710
(1902)). Since this temperature is lower than the boiling-point
of either of the two components, it is impossible to obtain a pure

FIG. 14.
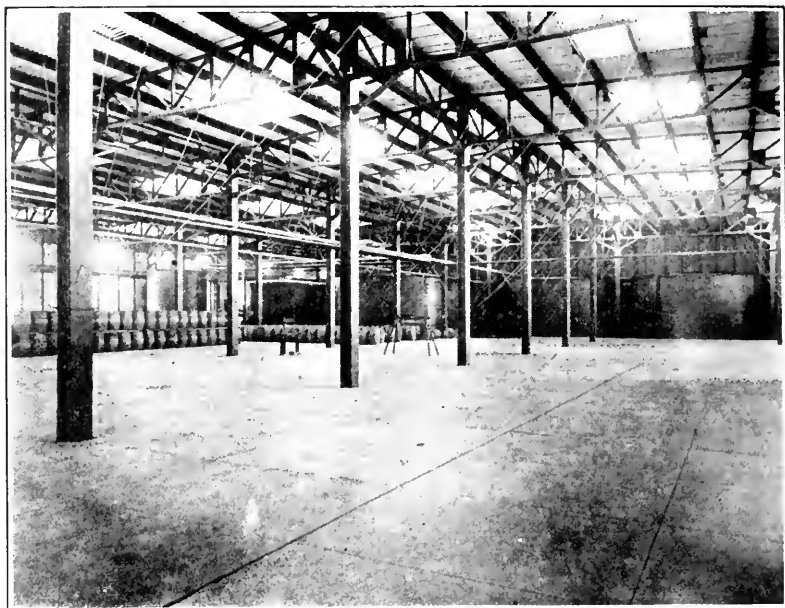
Modern bonded alcohol warehouse.

FIG. 15.
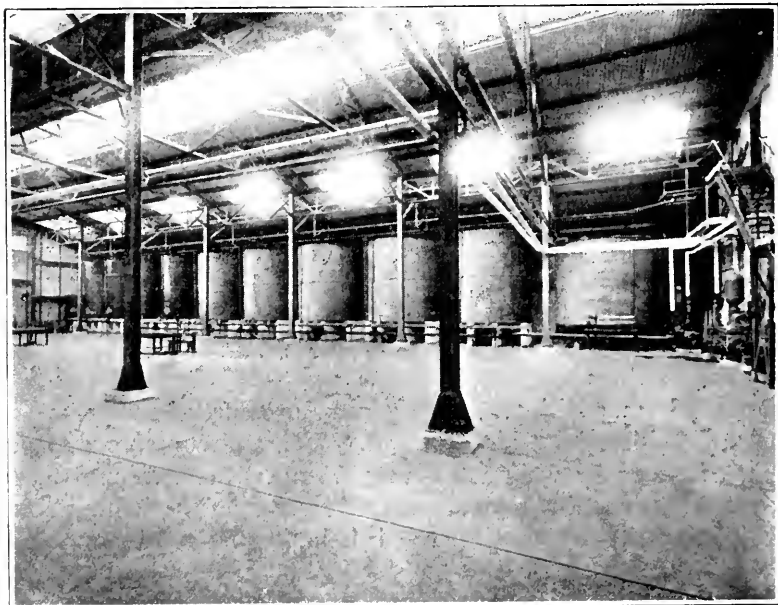
Present type of denaturing warehouse.

alcohol from a dilute aqueous solution by fractional distillation only.

The illustrations show better than words the development of distillation and rectification, and they also indicate the complexity and elaborateness of the present-day type of apparatus.

In the United States there are a large number of rules and regulations determining the details of control and operation of

FIG. 16.
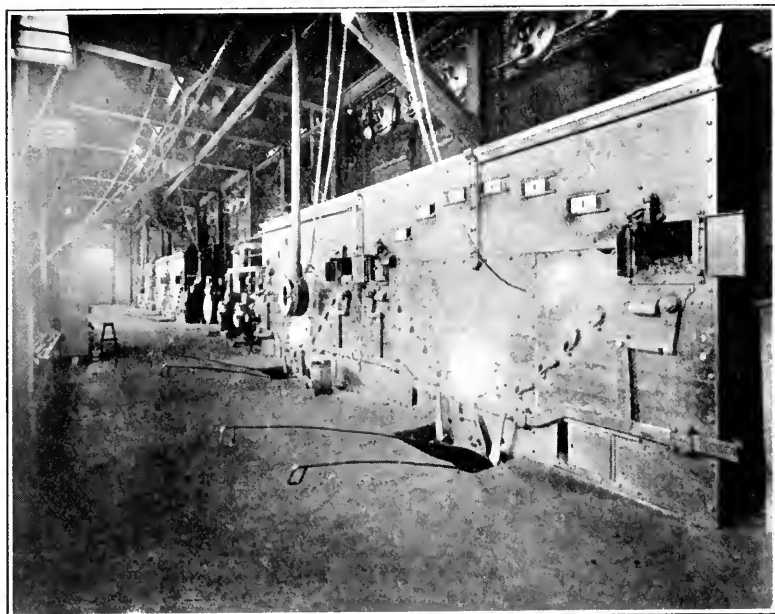
Boiler house of alcohol plant containing ten 600 H. P. boilers.

an alcohol distillery. In the larger industrial distilleries these rules oftentimes constitute an item of considerable expense. When they were made most of them had particular reference to the small distilleries having a capacity of but a few gallons of alcohol and they are burdensome in the large distilleries having a capacity of several million proof gallons per year.

PRODUCTION AND DISTRIBUTION.

In this country the production and distribution of industrial alcohol is so regulated that the cost of the alcohol to the consumers is materially increased.

The rules and regulations which have been recently released by the U. S. Internal Revenue Bureau, have removed to a great extent the antiquated regulations by which the industry has been hampered until the present year. These restrictions were an outgrowth of the old attempts to prevent the production of " illicit " whiskey, and it is gratifying to know that the Government has at last realized that these rules had no place in governing the procedure of the large industrial distillers of to-day.

The manufacturers and users, however, who, because of their product or processes, must use pure ethyl alcohol, are still greatly hampered because they must obtain their alcohol through the organization and under the same regulations that govern the sale, distribution, and use of whiskey. It is to be hoped that the Government may relieve the manufacturers of lawful goods unfit for beverage purposes of some of this " red tape " and the attendant taxes.

In considering the production of alcohol, it is interesting to notice the production of some of the foreign countries, and also to compare the production in some of them with that of the United States.

Germany.

Germany has been one of the largest producers and users of industrial alcohol. Because of war conditions, only statistics up to the year 1914 are available. The following table indicates the use of *tax-free* alcohol in 1911 and 1912:

TABLE I.

Consumption of Tax-free Alcohol in Germany.

Kinds of tax-free alcohol	United States gallons of pure alcohol	
	1911	1912
Completely denatured:		
With general denaturing formula.........	25,907,033	30,975,120
With benzol mixture...................	1,154,604	1,224,775
Incompletely denatured:		
With 5 liters wood alcohol..............	503,105	422,426
With 0.5 liter turpentine...............	27,667	36,642
With other denaturants................	8,798,962	8,115,043
Without denaturation:		
For hospitals and similar institutions.....	137,702	144,170
For public scientific institutions.........	50,635	54,146
For military technical institutions.......	287,866	266,093
For gunpowder and fulminate factories....	278,309	316,932
Total........................	37,145,883	41,549,348

The above table gives only the figures for tax-free alcohol and does not take into account the alcohol used for industrial purposes upon which a tax may have been paid.

The above undenatured alcohol was pure ethyl alcohol, sold and used under Government supervision.

The total production of alcohol from the various raw materials is indicated in Table II.

TABLE II.

Production of Alcohol in Germany.

Years	Potatoes distilleries, U. S. gals.	Yeast distilleries, U. S. gals.	Grain distilleries, U. S. gals.	Molasses distilleries, U. S. gals.	Fruit and other distilleries
1887/88–1891/92	59,826,000	10,190,000	3,065,000	3,330,000	686,000
1892/93–1896/97	63,362,000	10,370,000	3,615,000	3,620,000	898,000
1897/98–1901/02	81,730,000	10,900,000	4,750,000	3,190,000	872,000
1902/03	70,000,000	11,500,000	4,990,000	2,350,000	502,000
1903/04	80,420,000	12,060,000	6,204,000	4,410,000	608,000
1904/05	75,900,000	12,720,000	7,500,000	285,000	976,000
1905/06	92,820,000	12,670,000	7,000,000	219,000	819,000
1906/07	73,620,000	12,540,000	7,240,000	235,000	792,000
1907/08	83,100,000	12,770,000	6,440,000	272,000	1,005,000
1908/09	90,220,000	11,900,000	6,310,000	229,000	1,267,000
1909/10	77,600,000	9,460,000	6,150,000	1,936,000	1,005,000
1910/11	74,100,000	8,130,000	6,230,000	2,360,000	739,000
1911/12	66,000,000	7,925,000	13,100,000	3,380,000	898,000

CHART I.
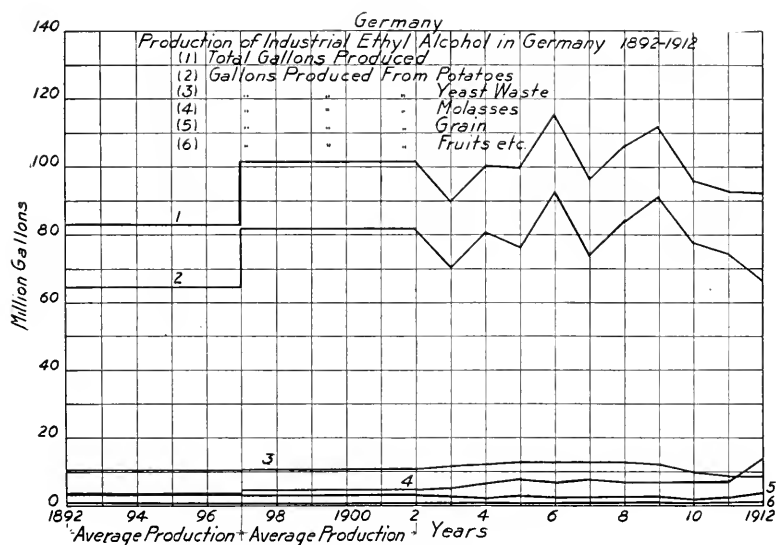
Crampton, in his report on alcohol (" Production and Use of Denatured Alcohol "—Department of Commerce Publication —Special Agents' Series, No. 77), illustrates clearly the uses and consumption of *incompletely denatured alcohol* for two years which are typical of the pre-war period (Table III).

TABLE III.

Consumption of Incompletely Denatured Alcohol in Germany.

Industrial uses	United States gallons of pure alcohol	
	1911	1912
Manufacture of vinegar	3,958,574	3,953,928
Manufacture of vinegar for industrial purposes and for manufacture of acetates	160,961	86,777
Brewers' glaze	28,301	34,798
Finishing of rubber goods	2,323	2,165
Celluloid and pegamoid	1,396,111	1,105,975
Synthetic camphor	6,283	10,111
Sulphuric ether	916,766	859,162
Sensitive films, paper, and plates for photographic purposes	36,986	55,651
Electrode plates for electrical accumulators	1,214	26
Acetic ether	8,131	15,074
Adhesive preparations	1,373	554
Coal-tar colors, including by-products	208,058	219,991
Solutions of coal-tar colors, for dye printing	14,045	8,897
Material for ligatures	19,229	19,219
Other substances enumerated under d, section 4, of the regulations	788,093	649,757
Chloroform	2,825	5,861
Iodoform	5,623	5,491
Ethyl bromide and bromoform	1,162	1,822
Iodine or bromine containing fats for medicinal uses	2,350	2,270
Lac dyes	192,166	109,903
Stamping colors and inks	. . . .	. . . .
Brewers' pitch	106	106
Feeding of gas lamps	3,643	1,399
Finishing of silk ribbons	14,034	2,086
Cleaning of jewelry and fine metal ware	2,429	1,109
Lacquers of all kinds (exclusive of brewers' glaze and lac dyes)	904,068	840,365
Scientific preparations for teaching purposes	2,297	2,376
Solid soaps	76,586	70,224
Wool fats and oils	19,272	20,143
Other purposes	31,933	28,802
Total	8,804,942	8,114,042

As the *incompletely* denatured alcohol is used under Government supervision, it is possible to obtain the above data as to uses. The above, however, represents but a small part of the

denatured alcohol, and the data for the completely denatured alcohol is not available.

Germany, more than any other nation, makes extensive use of the privilege of tax-free alcohol. This is probably due, in part,

CHART II.
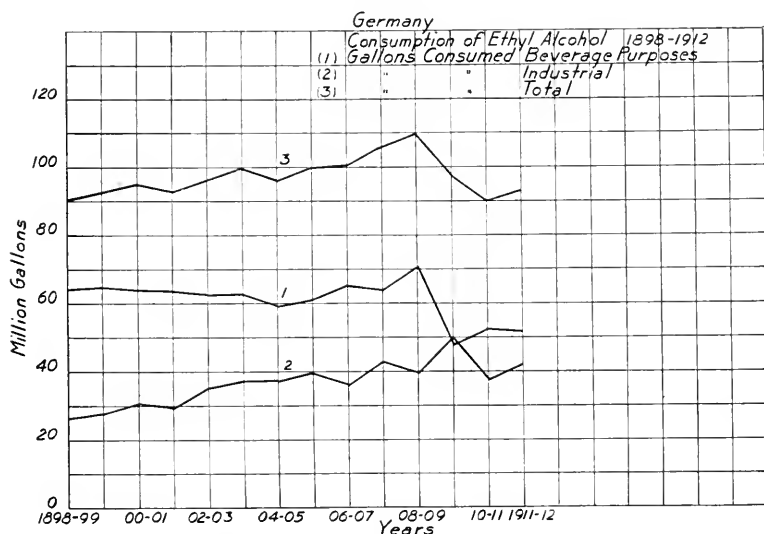
to her remarkable industrial expansion in recent years. Undoubtedly this expansion and production of alcohol was of great value and advantage to Germany in the recent war.

France.

In France the production and use of alcohol for industrial purposes has increased to a very marked degree. Statistics on the consumption of alcohol for industrial purposes have been published by Dachemin (*Bull. Soc. d'encour. Ind. Nationale*, vol 125) and are given in Table IV. Data on the consumption of tax-free alcohol during six years (1908–1913) have been included in a report by M. L. Calvert of the Paris Laboratory of the Ministere des Finances, and are presented in Table V.

United Kingdom.

In Table VI are given the figures for the consumption of methylated spirits in the United Kingdom during the five years ended March 31, 1913. This industrial methylated spirit is de-

TABLE IV.

Consumption of Alcohol for Industrial Purposes in France.

	1895 U. S. gallons	1900 U. S. gallons	1905 U. S. gallons	1910 U. S. gallons	1911 U. S. gallons	1912 U. S. gallons	1913 U. S. gallons
Heating and lighting	1,865,000	3,330,000	8,320,000	11,970,000	3,260,000	12,650,000	13,500,000
Varnishes	312,500	389,500	364,500	369,000	385,000	421,500	435,000
Cabinet furnishings	24,700	72,600	40,400	35,300	23,700	17,420	26,800
Plaster materials:							
Celluloid, etc.	58,000	190,000	562,000	504,000	494,000	480,000	472,500
Hat manufacture, etc.	14,160	10,900	6,020	17,900	15,770	18,050	26,650
Dyes and colors	4,860	4,120	14,600	21,400	21,600	20,400	22,600
Liquid rennet	2,975	3,245	3,910	4,645	4,570	4,900	5,170
Collodion	3,725	4,910	11,000	166,700	101,700	58,500	22,850
Chloroform	6,310	1,372	4,920	13,590	7,150	17,550	13,950
Chloral	4,410	8,130	10,080	5,175	1,820	2,320	2,340
Tannins	3,935	13,080	14,950	76	76	....	....
Various products:							
Chemicals and pharmaceuticals such as ether alkaloidal extracts, insecticides, transparent soap, etc.	14,250	101,800	178,600	95,000	86,900	113,300	124,400
Scientific uses, etc.	8,640	10,100	31,500	9,190	8,080	7,080	8,760
Fulminates, ethers, and explosives	1,223,000	1,712,000	2,957,000	3,620,000	3,390,000	4,111,000	4,460,000

TABLE V.

Consumption of Tax-free Alcohol in France.

Uses	United States gallons of pure alcohol					
	1908	1909	1910	1911	1912	1913
Heating and lighting	11,791,798	12,557,752	11,996,978	13,274,501	12,654,312	13,571,683
Varnishes	346,368	350,064	369,811	384,938	421,450	436,932
Thinning purposes	25,502	31,310	35,323	21,226	17,424	26,924
Plastic materials (celluloid fibrolithoid)	304,154	384,674	504,108	492,730	489,113	474,482
Hat making	14,546	15,391	17,926	1,531	18,058	26,738
Dyes and colors	12,645	19,219	21,226	21,330	20,407	22,604
Liquid rennet	4,224	4,752	4,646	4,620	4,963	5,194
Collodion	20,275	32,551	30,545	35,772	47,731	22,869
Artificial silk	306,372	340,164	177,382	101,297	58,582	7,764
Chloroform	5,914	5,095	13,596	7,154	17,556	14,018
Chloral	3,960	4,303	5,174	1,822	2,323	2,332
Tannins	766	53	792	792	....	....
Various products: Alkaloids, extracts, insecticides, transparent soaps, etc.	63,994	73,920	93,984	76,882	113,441	124,927
Scientific uses	9,715	8,210	11,827	8,078	7,075	8,798
Ethers, fulminate of mercury, explosives, etc.	3,134,050	3,459,588	3,613,632	3,393,139	4,110,850	4,447,309
Total	16,044,283	17,287,046	16,896,950	17,825,812	17,983,285	19,192,574

Chart III.

France

Total Gallons Ethyl Alcohol Produced in France 1895-1913

Chart IV.

France

Consumption of Denatured Alcohol in France 1895-1913
(1) Total Gallons Consumed
(2) Gallons used, Light and Heat
(3)   "   "   Explosives etc.
(4)   "   "   Paint, Varnish, Celluloid, etc.
(5)   "   "   Chemicals, Drugs, Extracts etc.

Chart V.

Great Britain

Chart VI.

United States
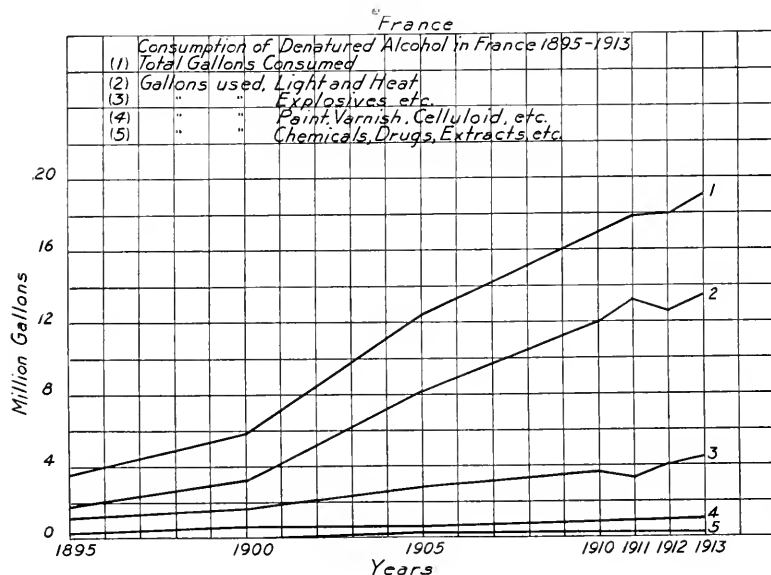
natured by adding to 95 volumes of alcohol (90 to 95 per cent. strength) 5 volumes of wood alcohol of an approved type. It is used in the manufactures under bond and is not allowed to be sold or used outside of the bonded premises.

<div align="center">Table VI.</div>

<div align="center">Consumption of Methylated Spirits in the United Kingdom.</div>

Year ended March 31	Industrial imperial gallons, 1.2 U. S. gallons	Mineralized imperial gallons, 1.2 U. S. gallons	Total imperial gallons, 1.2 U. S. gallons
1909...............	2,542,911	1,628,191	4,171,102
1910...............	2,404,019	1,558,393	3,962,412
1911...............	2,877,429	1,688,313	4,565,742
1912...............	3,091,463	1,720,031	4,811,494
1913...............	2,846,234	1,582,967	4,429,201

Mineralized methylated spirit is denatured by adding to 90 volumes alcohol 10 volumes of wood alcohol and three-eighths volume (0.375 per cent.) of an approved mineral naphtha. The latter is of a type that corresponds closely to the ordinary kerosine used in the United States. The mineralized methylated spirit is sold to the general public for heating, lighting and cleaning purposes.

Table VII shows the uses to which industrial alcohol (that is, alcohol used under bond which represents a part of the total used for industrial purposes) is put in the United Kingdom and the quantities consumed in the various industries for the years ended March 31, 1911–1913.

<div align="center">United States.</div>

The Commissioner of Internal Revenue, in his report for 1919, states the quantities of the various raw materials used in the several states for the manufacture of alcohol, including beverage alcohol; Table VIII is based on this report. The quantities of alcohol, including beverage alcohol, which were obtained from these raw materials, are shown in Table IX. A summary of the materials used and the spirits produced therefrom during each of the fiscal years (ending on June 30) from 1913 to 1919, both included, may be found in Table X; it is of interest to compare the data for 1918 or 1919 with the average for the preceding five years. During the past few years, the production and consumption of denatured alcohol in the United States has

CHART VII.

United States
Distilled Spirits Produced, Withdrawn, and Remaining in Bond
Years Ended June 30, 1909-1918

(1) Gallons Remaining in Warehouse
(2)   Produced
(3)   Withdrawn Tax Paid

CHART VIII.

Production of Ethyl Alcohol 1908-1912
(1) Gallons Produced in Russia
(2)   Germany
(3)   United States
(4)   Austria Hungary
(5)   France
(6)   Great Britain and Ireland
(7)   Italy
(8)   Sweden
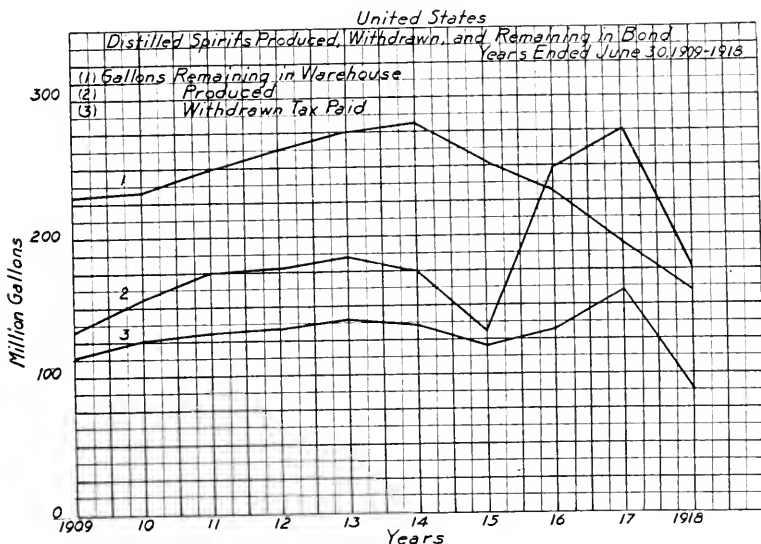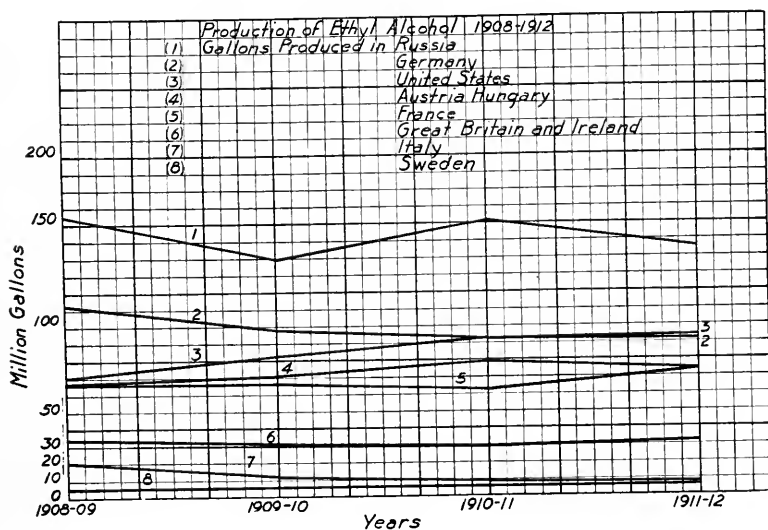
TABLE VII.

Consumption of Industrial Alcohol in the United Kingdom.

Industrial uses	Imperial gallons, 1.2 U. S. gallons		
In the manufacture of:	1911	1912	1913
Finish, for sale..........................	369,283	419,080	395,739
Varnishes for polishes or lacquers for sale........	940,186	1,030,262	983,694
Stains, paints, enamels, etc., for sale	61,176	63,242	67,546
Varnishes, finish, stains, polishes, lacquers, etc., or for polishing purposes in manufacturers' own workshops.....................................	294,343	316,863	300,325
Felt and other hats..........................	123,430	128,001	134,742
Celluloid, xylonite, and similar substances	24,003	28,729	28,818
Oilcloths, leather cloths, pegamoid and similar substances.....................................	151,184	173,203	215,937
Linoleum and similar substances..............	948	398	5,340
Smokeless powders, fulminates and other explosives	20,327	21,134	19,260
Soap..	144,884	160,166	180,708
Electric lamp filaments......................	13,151	11,835	9,151
Electric cables..............................	4,762	1,832	5,070
Incandescent mantles........................	18,176	33,169	16,175
Ether.......................................	192,878	212,058	198,113
Chloroform.................................	9,627	7,912	5,753
Ethyl chloride and bromide...................	747	652	806
Solid medicinal extracts.....................	56,720	58,438	53,663
Alkaloids and fine chemicals..................	22,868	33,856	32,486
Embrocations, liniments and lotions...........	32,230	33,302	34,106
Surgical dressings...........................	8,461	7,400	10,032
Capsules and other medicinal appliances........	1,846	1,190	2,016
Hair washes.................................	19,770	26,787	29,497
Cattle medicines............................	2,324	2,051	2,547
Plant washes, insecticides and sheep dips........	9,630	10,763	10,877
Aniline and other dyes:			
Solids.................................	874	1,515	211
Solutions..............................	4,382	1,526	2,345
Fireworks and matches.......................	5,207	4,785	3,107
Photographic plates and papers, and other photographic purposes...........................	42,294	43,425	46,144
Steel pens..................................	3,264	2,739	3,498
Silk, crape and embroidery...................	9,698	7,341	8,450
Artificial flowers, etc........................	4,435	4,695	5,060
Rubber.....................................	1,223	921	586
Artificial silk...............................	....	....	750
Ships' compasses, spirit levels, etc.............	952	1,433	1,081
Inks.......................................	2,558	438	799
Collodion..................................	8,302	5,331	8,191
Disinfectants...............................	220	1,866	2,311
Hop extract................................	....	....	19,000
Other uses:			
Dyeing and cleaning operations in laundries and dye works................................	46,992	45,394	42,170
Textile printing.............................	11,115	8,416	8,437
Preservation of specimens in museums and hospitals.................................	6,850	6,562	6,608
Educational and scientific purposes in colleges and schools...................................	6,150	6,435	5,821
Analytical and scientific purposes in the laboratories of analysts' works, chemists, etc.	4,836	6,577	5,691
For hospitals, asylums and infirmaries..........	43,662	47,216	51,213
Electrotyping and printing...................	553	1,450	1,132
Miscellaneous uses..........................	8,573	7,671	10,905
For admiralty dockyards and war office arsenals and workshops, chiefly for varnishes and polishes.................................	13,541	20,455	14,860
Total...............................	2,748,635	3,008,514	2,990,870

Table VIII.

Grain and Other Materials Used for Production of Distilled Spirits, Year Ended June 30, 1919, by States.

States	Corn	Rye	Malt	Other materials	Molasses	Dilute saccharine liquid	Total Bushels	Total Gallons
	Bushels	Bushels	Bushels	Bushels	Gallons	Gallons	Bushels	Gallons
California	988	......	......	......	11,714,888	......	988	11,714,888
District of Columbia	111,107	......	150,658	72,343	917,159	......	334,108	917,159
Illinois	2,752,509	4,259	268,324	......	12,868,046	......	3,025,092	12,868,046
Indiana	216,957	2,930	29,463	714	......	......	250,064	......
Kentucky	497,428	7,387	58,817	......	417,637	......	563,632	417,637
Louisiana	......	......	3	737	27,073,185	3,534,458	740	30,607,643
Maryland	......	......	129	......	21,289,577	......	129	21,289,577
Massachusetts	......	......	......	......	7,564,766	......	......	7,564,766
Montana	......	......	......	......	154,041	......	......	154,041
New York	42,830	898	5,229	......	33,554,286	......	48,957	33,554,286
Ohio	241,574	......	42,833	......	......	......	284,407	......
Pennsylvania	......	......	......	......	7,945,108	......	......	7,945,108
South Carolina	......	......	......	894	......	6,266,877	894	6,266,877
Wisconsin	26,954	9,830	17,790	10,936	......	......	65,510	......
Total	3,890,347	25,304	537,246	85,624	123,498,693	9,801,335	4,574,521	133,300,028
Total for fiscal year 1918	14,544,545	248,864	1,689,677	172,039	118,027,960	68,527,242	16,665,125	186,555,202

TABLE IX.

Production of Distilled Spirits, Years Ended June 30, 1918 and 1919, by States.

States and territories	1919			1918 Total production
	From materials other than fruit	Fruit brandy	Total production	
	Gallons	*Gallons*	*Gallons*	*Gallons*
California	8,129,788.8	1,765,905.7	9,895,694.5	14,023,646.00
Connecticut	....	36,516.6	36,516.6	26,450.6
District of Columbia	488,214.6	....	488,214.6	749,517.4
Hawaii	....	....	....	3,934.5
Illinois	26,265,840.4	....	26,265,840.4	49,680,080.3
Indiana	1,150,951.8	....	1,150,951.8	15,830,930.0
Kentucky	3,957,654.8	....	3,957,654.8	12,608,436.6
Louisiana	22,135,264.9	....	22,135,264.9	24,406,539.3
Maryland	16,078,605.5	....	16,078,605.5	26,746,386.2
Massachusetts	5,973,432.3	....	5,973,432.3	10,873,374.9
Michigan	....	....	....	752,744.5
Missouri	....	....	....	79,526.5
Montana	107,863.4	....	107,863.4	186,248.0
New Jersey	....	....	....	51.4
New York	6,956,436.6	....	6,956,436.6	10,544,901.1
Ohio	1,263,875.3	....	1,263,875.3	3,314,102.9
Pennsylvania	5,877,816.5	....	5,877,816.5	7,293,914.3
Rhode Island	....	....	....	2,845.0
South Carolina	378,227.2	....	378,227.2	943,567.7
Texas	....	....	....	7,281.3
Wisconsin	212,146.2	....	212,146.2	759,294.4
Wyoming	....	....	....	26.2
Total	98,976,118.3	1,802,422.3	100,778,540.6	178,833,799.1

Total production of distilled spirits, years ended June 30, 1914-1917.

1914 .... 181,919,542 gallons   1916 .... 253,283,273 gallons
1915 .... 140,656,103 gallons   1917 .... 286,085,463 gallons

TABLE X.

Annual Domestic Production of Alcohol from Various Raw Materials.

Years	Grain used	Spirits produced from grain	Molasses used to produce spirits	Spirits produced from molasses	Molasses used to produce rum	Rum produced from molasses	Dilute saccharine liquid used to produce spirits	Spirits produced from dilute saccharine liquid
	Bushels	*Gallons*	*Gallons*	*Gallons*	*Gallons*	*Gallons*	*Gallons*	*Gallons*
1913	34,039,277	155,757,827	61,194,333	26,844,710	3,446,643	2,750,846	....	....
1914	30,679,549	142,323,044	60,862,167	29,262,516	3,859,098	3,026,085	....	....
1915	19,138,118	89,553,291	119,467,918	39,736,548	3,833,578	2,844,313	....	....
1916	39,748,892	184,091,810	77,034,173	58,052,924	3,943,301	2,908,898	71,164,758	4,070,288
1917	40,669,819	188,238,880	108,843,878	82,460,340	3,653,755	2,881,414	78,462,969	3,094,324
Total 5 years....	164,275,655	759,964,852	427,402,469	236,357,038	18,736,375	14,411,556	149,627,727	7,164,612
Yearly average..	32,855,131	151,992,970	85,480,493	47,271,407	3,747,275	2,882,311	74,813,863	3,582,306
1918	16,655,125	86,025,257	116,167,599	83,293,277	1,860,361	1,464,021	68,527,242	2,603,918
1919	4,574,521	21,924,557	122,498,268	75,407,358	1,000,425	816,103	34,488,066	823,000

undergone a marked increase, as may be seen by reference to Table XI.

The falling off in the quantity of denatured alcohol used during 1918 and 1919 is accounted for by the fact that in the early part of the year 1918, several of the larger munition plants discontinued the manufacture of explosives for the Allies, in which denatured alcohol had been used, and engaged in the

TABLE XI.

Domestic Production of Denatured Alcohol.

Fiscal years	Denaturing warehouses	Completely denatured	Specially denatured	Total	
		Wine gallons	*Wine gallons*	*Wine gallons*	*Proof gallons*
1907	8	1,397,861	382,415	1,780,276	3,084,950
1908	12	1,812,122	1,509,329	3,321,451	5,640,331
1909	12	2,370,839	2,185,579	4,556,418	7,967,736
1910	12	3,076,924	3,002,102	6,079,027	10,605,870
1911	14	3,374,019	3,507,109	6,881,129	11,682,887
1912	14	4,161,268	3,933,246	8,094,515	13,955,903
1913	21	5,233,240	4,608,417	9,831,658	16,953,552
1914	25	5,213,129	5,191,846	10,404,975	17,811,078
1915	23	5,386,646	8,599,821	13,986,468	25,411,718
1916	33	7,871,952	38,807,153	46,679,106	84,532,253
1917	44	10,508,919	45,170,678	55,679,597	93,762,422
1918	49	10,328,454	39,834,561	50,163,016	90,644,722
1919	45	9,976,721	28,294,219	38,270,940	59,976,575

manufacture of explosives for the United States Government, using principally tax-free undenatured alcohol. The Army specifications were subsequently changed, and denatured alcohol was used exclusively in those plants. The quantity of denatured alcohol used during the year 1918 in the manufacture of explosives and for other war purposes was approximately 52,847,-117 proof gallons.

USES OF INDUSTRIAL ALCOHOL.

Every chemist realizes the impossibility of even enumerating all of the uses of alcohol; the more study one gives to the uses of alcohol the more he is impressed with the great multitude of products of all descriptions which depend directly or indirectly on the use of alcohol in their manufacture.

USE OF ALCOHOL AS A SOLVENT.

Undoubtedly the most important use of alcohol is that of a solvent. Chemists and pharmacists are convinced that the only solvent which is of even equal importance is water.

The use of alcohol as a solvent in the manufacture of nitro-cellulose, and in purification processes, has been demonstrated during the war in the manufacture of munitions. Alcohol as such is not a solvent for nitrocellulose, but when mixed with ether it is used in large quantities in the manufacture of smokeless powders and collodion.

Alcohol as a solvent for dyes and confectioner's colors is of great importance. The development of gelatine food products has also called for considerable quantities of alcohol as a solvent for the coloring matter and as a vehicle for its introduction. A great many colors are sold in the form of a solution in alcohol or a paste.

No suitable substitute has ever been found for many of these uses of alcohol; and if that compound were not available, many industries would be greatly restricted, and many others would cease to exist. If it were not for the solvent properties of alcohol we should have very few of such things as perfumes, liquid soaps, toilet waters, liniments, flavoring extracts, etc.

Practically all of the paint and varnish removers on the market depend, for their action, to a greater or less extent upon the solvent properties of alcohol; and many of the shellacs and varnishes themselves are made up with alcohol as a solvent and thinner.

ALCOHOL AS A FUEL.

The United States has been very fortunate indeed in that it has had very abundant supplies of petroleum. For that reason alcohol has not been used very extensively for fuel and power purposes. However, these supplies of petroleum are not inexhaustible, and already steps towards the conservation of these resources have been taken. The United States Geological Survey, after a very careful analysis of the situation, finds that the reserves above ground are being rapidly depleted. They predict that the peak in petroleum production will be reached in from two to three years, and that after that time there will be a gradual decline in production over a period of years.

Although the petroleum resources are being depleted, the raw materials for the production of alcohol are about us in inexhaustible quantities; and these resources may be renewed constantly. Alcohol is a very superior fuel in that it burns with a smokeless flame and does not carbonize like kerosene; and even

at the present time, its only rival for chafing dishes, coffee percolators, and such articles is electricity.

In regions where electricity is not available alcohol has no rival for cooking, heating, lighting and many other purposes. Alcohol when burned under a Welsbach mantle, which depends upon heat for its luminosity, makes a most satisfactory light. It gives three and a half times as much light as the same volume of kerosene when burned in a good oil lamp. The cleanliness and freedom from odor make alcohol very desirable for this purpose.

Concerning the utilization of alcohol for power purposes there is still much to be said. On account of our enormous petroleum resources, no great amount of alcohol has been used in the United States for power purposes, but such use has been very extensive abroad. However, as our petroleum resources become exhausted, alcohol as such, and in admixture with other products, will assume a very important rôle among the fuels for power purposes, especially in the automotive field. Even though it is true that, pound for pound, gasoline has a higher calorific value than alcohol, yet, under the conditions found in ordinary gasoline engines, the theoretical power is never developed. This has been especially true during the last two or three years, since the gasoline has included more of the higher boiling compounds, and vaporization and atomization of the fuel has become increasingly difficult. The point has now been reached where the average gasoline engine utilizes only a relatively small portion of the fuel used. Thus, if an engine burning gasoline be compared with a properly-designed engine using alcohol as fuel, it is found that the power developed per gallon of fuel is about the same. As the price of gasoline increases and as its quality becomes poorer, both of which will happen according to the U. S. Geological Survey, alcohol will attain an ever-increasing importance in this field. An instance may be cited to show the possibilities of the use of alcohol in admixture with other components for motor fuel purposes. During the last year at least one of the larger producers of industrial alcohol has devoted some attention to the production of an alcohol fuel. A mixture of alcohol, gasoline and other components has been developed which possesses remarkable properties, and is much more efficient as a fuel, when compared with gasoline under identical conditions.

The above statements are emphasized by the results obtained by the Post Office Department. The planes used in the United States Post Office Airplane Mail Service are being operated with an alcohol fuel. The Post Office Department tests show a great increase in the number of miles per gallon, an increase in power, and a very marked saving in the quantity of lubricating oil used.

The following is an analysis of the consumption of alcohol fuel at the various speeds, the tests covering thirty-one non-stop flights between New York and Washington:

1440–1460 r. p. m.	15.9	gal. per hour
1475–1480 r. p. m.	20.1	gal. per hour
1500 r. p. m.	21.5	gal. per hour
1520–1525 r. p. m.	22.44	gal. per hour

A comparative analysis of the fuel consumption with gasoline and alcohol fuel at different engine speeds follows:

R. P. M.	1440-1460	1475	1500
Gasoline		24	24.17
Alcohol fuel	15.9	20.1	21.5

The following is a comparative analysis of lubricating oil consumption at different engine speeds:

R. P. M.	1440-1460	1475	1500
Gasoline		4.65	4.95
Alcohol fuel	4.5	4.2	4.2

These tests also show much less carbon formation than when using gasoline; and the number of forced landings due to fouled spark plugs has been reduced to a minimum.

The U. S. Bureau of Standards has been making exhaustive tests on blended alcohol fuels. The results of these tests are available at that Bureau and are indeed indicative of the superiority of these alcohol fuels over those ordinarily obtainable.

The following quotation concerning the use of this alcohol by the Post Office Department is from *The Journal of the Society of Automotive Engineers* (vol v, No. 3, p. 207) :

A new alcoholic fuel, consisting of alcohol, benzol, and ether, is about to take the place of the high-grade airplane gasoline, which has previously been used in the Air Mail Service.

The advantage of this fuel lies in the resulting cleanliness of the engines, reduction of the cost of upkeep and its burning cooler than gasoline, which, to some extent, overcomes the objection to a high-compression

engine when operating at low altitudes. It requires about four-fifths as much of the new fuel for any given distance and altitude. This gives greater flying radius to the planes and will enable the De Haviland Fours to cover the New York to Cleveland route, a distance of 430 miles, in a non-stop flight. It reduces the probability of forced landings by keeping the spark-plugs and the engine cylinders clear of carbon deposits and accumulations of oil.

ALCOHOL AS A RAW MATERIAL IN CHEMICAL PROCESSES.

A great many chemical processes depend directly on alcohol as a raw material. Probably, in normal times, the most important and extensive use of this type is the manufacture of the ethyl esters. These esters are used very extensively as solvents in the production of pyroxylin plastics, films, artificial leather, celluloid, etc.

In the world war enormous quantities of alcohol were used as raw material for the production of toxic gases such as mustard gas. The mustard gas was formed as follows:

By a process of catalytic dehydration ethylene was formed from alcohol. The ethylene was then passed through sulphur monochloride S_2Cl_2 when combination took place forming mustard gas.

$$\begin{matrix} C_2H_4 \\ C_2H_4 \end{matrix} + S_2Cl_2 \longrightarrow \begin{matrix} ClC_2H_4 \\ ClC_2H_4 \end{matrix} S + S$$

Dichlor-diethyl sulphide
or
Mustard Gas
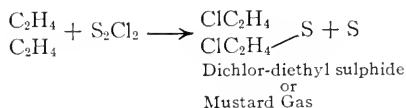
Other very important uses of alcohol as raw material occur in the manufacture of ether, mercury fulminate, chloroform, acetphenetidin, and a very large number of other drugs and chemicals. Alcohol is used as a raw material for the production of acetaldehyde. The aldehyde is formed directly by the catalytic oxidation of alcohol in a tubular retort.

ALCOHOL AS A GENERAL UTILITY.

The innumerable uses of alcohol in the hospital, in the chemical laboratory, and in the home are so well known to almost everyone that even a mention of them seems unnecessary. How many of our hospitals could operate effectively without the use of alcohol? How many of our chemical laboratories could carry on their work successfully without the use of alcohol? Alcohol is so useful about every household, for such purposes as a fuel, for

cleaning and as an ablution, that even if not a necessity it would be an inconvenience if necessary to do without it.

MISCELLANEOUS USES OF ALCOHOL.

Alcohol is used in large quantities as a dehydrating agent in the manufacture of photographic films and in the preparation of photoprints.

Oftentimes in cases of substances insoluble in alcohol, alcohol is very valuable as a precipitating and purifying agent. Among such products may be mentioned glycero-phosphates, casein and milk protein, lanolin, etc.

Alcohol is frequently necessary as a solvent in the manufacture of such things as inks, celluloid and shellac cements, disinfectants, etching solutions, soldering fluxes, etc.

Alcohol as such, and in admixture with other compounds, has been used extensively as a carbon remover. The carbon deposits formed in the cylinders of automotive engines resist the action of most solvents. Alcohol and a few other compounds seem to have the property of acting as a solvent for the binder of such deposits, thus freeing the carbon and siliceous materials which are allowed to blow out through the engine exhaust.

The U. S. Bureau of Standards has made exhaustive tests of all the important anti-freeze preparations for preventing the freezing of the water in radiators of automotive apparatus. After this careful study they recommend the use of alcohol. Practically all of the high-class motor-car manufacturers recommend the use of alcohol for this purpose. Most anti-freeze preparations contain calcium chloride, which causes excessive corrosion of the cooling system according to the Bureau of Standards; this statement is supported by the recent discussion of the question at the Buffalo meeting of the American Chemical Society. Alcohol is no more corrosive than pure water and its use as an anti-freeze is becoming very extensive.

Alcohol is used in the preparation of all forms of manufactured tobacco. Practically all of the so-called " casing " solutions are made up with alcohol.

FUTURE OF INDUSTRIAL ALCOHOL.

The future of industrial alcohol is only limited by the restrictions which may surround its use. Now that the United States

has gotten a start in the chemical and allied industries in which alcohol is an absolute necessity. development should be rapid and extensive.

After the passage of the industrial alcohol law in 1906 the effect on American industries was marked. Many new enterprises were undertaken, and those in operation were greatly expanded. An export trade was undertaken and developed until to-day the export of alcohol, and products in the manufacture of which alcohol is a necessity, is a very important factor.

The Internal Revenue Bureau regulations which have just been released make possible the utilization of alcohol for industrial purposes to a greater extent than ever before. For example, it is now possible for chemical laboratories to obtain pure ethyl alcohol free of tax for use in scientific research. It is also possible for schools, colleges, hospitals and sanatoriums to obtain alcohol free of tax.

Some of the needless formalities surrounding the manufacture, sale, and use of denatured alcohol have been eliminated, and the manufacturer using alcohol is thereby helped. May we not hope that the Internal Revenue Bureau will continue its present open-minded policy and encourage the proper use and regulation of industrial alcohol.

CONCLUSIONS.

Although a treatise of several volumes would be required to discuss industrial alcohol in a thorough manner, yet it is hoped that a few suggestions have been given which will indicate to the reader the nature and scope of the alcohol industry and the vast number of other industries in which industrial alcohol is a necessity, and that a realization of the great importance of industrial alcohol will be acquired.

Now that the world at large realizes in a measure the difference between beverage and industrial alcohol, may we not look for favorable legislation concerning industrial alcohol and a stimulation of those industries which have not yet attained their proper expansion in the United States? May our industries using alcohol be enabled to compete with those of any other country.

THEORY AND PRACTICAL ATTAINMENTS IN THE DESIGN AND USE OF RADIO-DIRECTION FINDING APPARATUS USING CLOSED COIL ANTENNAS.*

BY

A. S. BLATTERMAN.

Captain Signal Corps, U. S. Army.

(SUPPLEMENTARY NOTE.)

INFORMATION concerning coil receivers for wave-lengths below 1000 metres has already appeared in this JOURNAL [1] in connection with the data for longer wave-lengths. The following results on 4' and 6' loops for $\frac{1}{4}''$ and $\frac{7}{16}''$ wire spacing, respectively, which values correspond to the best values of spacing for these sizes of loops as determined by the curve, Fig. 21, page 309, of the original paper, have recently been obtained:

Four-foot Loop—$\frac{1}{4}''$ Spacing.

Four turns.		Seven turns.		Ten turns.	
Wave-length.	Resistance.	Wave-length.	Resistance.	Wave-length.	Resistance.
220 metres	14.8 ohms	330 metres	10.5 ohms	450 metres	13.2 ohms
275 metres	3.95 ohms	390 metres	7.5 ohms	600 metres	6.8 ohms
350 metres	2.65 ohms	450 metres	5.55 ohms	800 metres	4.55 ohms
450 metres	2.15 ohms	600 metres	3.6 ohms	1000 metres	3.6 ohms
600 metres	1.6 ohms	1000 metres	2.5 ohms	1400 metres	2.8 ohms
800 metres	1.4 ohms				

Six-foot Loop—$\frac{7}{16}''$ Spacing.

Three turns.		Five turns.		Seven turns.	
180 metres	11.4 ohms	275 metres	20.0 ohms	400 metres	20.0 ohms
260 metres	5.5 ohms	305 metres	12.9 ohms	550 metres	8.6 ohms
360 metres	3.4 ohms	400 metres	6.5 ohms	750 metres	6.0 ohms
500 metres	2.5 ohms	500 metres	4.6 ohms	1200 metres	3.4 ohms
750 metres	2.0 ohms	750 metres	3.0 ohms		
1000 metres	1.9 ohms				

Ten Turns.

660 metres	22.6 ohms
600 metres	17.2 ohms
750 metres	10.5 ohms
1000 metres	6.5 ohms
1500 metres	4.4 ohms

* Communicated by Maj.-Gen. George Owen Squier, Chief Signal Officer, U. S. A.

[1] Vol. 188, page 289 (September, 1919).

Motor Transportation in Palestine. (*Scientific American,* August 7, 1920, p. 121.)—The camel is being superseded by the motor vehicle and soon cars and trucks will be numerous in the streets of Jerusalem and other ancient cities of Palestine, and will also be employed for interurban transportation. The slow-moving, but fairly reliable, camel is to be replaced by the faster and more reliable motor truck mechanism. The problem of transportation not only in Jerusalem but throughout Palestine is acute. The railroads are few in number and uncertain in their schedules. Most of the passenger service of these roads was suspended during the war except for the use of troops. These roads are now in such a condition as to make other means of transportation necessary. The English since their occupation have been building up the important ports of Palestine and are planning to operate a fleet of motor trucks to these places to accommodate the influx of tourists to the birthplace of Christianity and to accommodate commercial travellers. A service from Jerusalem to Damascus in Syria is also being planned.

Preservation of Eggs.—HILTON I. JONES and ROBERT DU BOIS of the Oklahoma Agricultural and Mechanical College (*Journal of Industrial and Engineering Chemistry,* 1920, xii, 751–757) divide the methods for the preservation of eggs into four classes: (1) Cold storage; (2) air-tight packing; (3) sealing with various agents, and (4) immersion in preservative solutions. Of the various sealing agents, aluminium soap was found the most efficient. When gasoline was used as a solvent for this soap, the shell eggs were dipped first in dilute sulphuric acid, then in the soap solution; by this procedure the eggs remained free from any taste of gasoline. When chemically pure pentane was used as the solvent, the soap solution alone was applied to the eggs. Pentane was readily obtained by hydrogenation of amylene which was prepared from technical fusel oil. Exposure of the eggs to a high vacuum (several mm. of mercury) without the use of a preservative exerted a bactericidal action, but did not entirely preserve the eggs.   J. S. H.

Kelp distillates have been studied by G. C. SPENCER (*Journal of Industrial and Engineering Chemistry,* 1920, xii, 786–792). In the destructive distillation of kelp in closed retorts for the recovery of potassium chloride and iodine, a tar is obtained which may be separated into tar acids, neutral oils, ammonia, and pitch. The crude tar creosote (tar acids) has a high toxicity and may be used as a disinfectant. The residual kelp oil has value as a flotation oil. The pitch residue from the distillation of the tar is a source of nitrogen for Prussian blue and other compounds of cyanogen. The aqueous liquor, obtained in the distillation, contains ammonia in workable quantities.   J. S. H.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

ENAMELS FOR SHEET IRON AND STEEL.[1]

By J. B. Shaw.

[ABSTRACT]

THIS is a general treatise dealing with the technology of enameling of sheet iron and steel. It has been prepared to answer the demand for a general treatise dealing with the technology of the manufacture of vitreous enamels for these metals. This subject is not treated adequately in any existing publication.

From the standpoint of mechanical equipment the sheet-iron and steel enameling industry has been probably the most progressive of all ceramic industries in the United States. The presses and machinery used for working the steel and forming the shapes are unsurpassed in ingenuity by those used in any other industry, and are constantly being improved. In this respect the sheet-metal enameling industry of this country has led the world. In the strictly ceramic lines of the industry having to do with the preparation and application of the enamels, progress has been less rapid. Up to a few years ago there was very little work carried on and this little was seldom reported in print. Recently there has been a decided change in this respect. Representatives of the enameling industry have been joining the ceramic technical societies, have been contributing rather liberally to the journals of these organizations, and have been showing a decided interest in developing the technology of sheet-metal enameling. The leading manufacturers of the country are realizing that the sheet-iron enameling industry has reached the limit of development possible so long as it depends upon formulas rather than upon men with technical training which will enable them to improve and manipulate these formulas to meet varying conditions.

In collecting data for this paper an effort has been made to obtain reliable and authentic information wherever available and

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* Communicated by the Director.
[1] Technologic Paper No. 165.

to correlate it in such a manner as to shed some light on the problems encountered by enamelers. The treatise is a compilation of data dealing with the subject of enameling from various publications, from the notebook of the author, from the files of the Bureau, and from the experience of men engaged in the enameling industry in this country.

Among the subjects dealt with in connection with the properties and preparation of steel for enameling are physical and chemical requirements, sand blasting, treatment preliminary to pickling and methods of pickling. A chapter is devoted to the properties of the raw materials used in compounding enamels. The relations between chemical composition and physical properties of enamels are discussed fully. The procedure used in the preparation, applying and firing of enamels are described in detail. The calculation of enamel formulas is fully explained and examples are given. The physical properties of enamels are dealt with in some detail and resistance of enamels to chemical action is fully discussed.

ADJUSTMENT OF PARABOLIC AND LINEAR CURVES TO OBSERVATIONS TAKEN AT EQUAL INTERVALS OF THE INDEPENDENT VARIABLE.[2]

By Harry M. Roeser.

[ABSTRACT]

LEAST squares reductions of observations that follow a parabolic or linear law taken at equal intervals of the independent variable frequently occur in physics and engineering practice. Makeshift devices are often employed to evade the arithmetical work of determining the constants of curves which properly represent such data.

In this paper the ordinary least squares formulas are subjected to mathematical treatment and rigorous solutions are evolved which require an ultimate minimum of arithmetical work. A table is furnished from which a large portion of the solutions can be written down from inspection of the observations.

Application of the solutions is made to typical problems and an absolute check with the regular least squares solutions is shown.

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[2] Scientific Paper No. 388.

THE MEASUREMENT OF DIFFUSE REFLECTION FACTORS AND A NEW ABSOLUTE REFLECTOMETER.[3]

By A. H. Taylor.

[ABSTRACT]

The diffuse reflection factor of a surface is the numerical value of the ratio of the total reflected light flux to the incident light flux.

The measurement of reflection factors of surfaces such as walls and ceilings is of considerable value in planning the lighting of offices, etc. Previous to this time there has been no accurate and convenient instrument available for this purpose. Several methods have been used in making such measurements in the laboratory, but most of them have been incorrect, on account of an erroneous value assigned to the standard surface. Hence it is apparent that an " absolute " reflectometer (one not requiring a reproducible standard surface) which is both reliable and portable would fill a very real need. Such an instrument has been developed and tested by the author, with satisfactory results.

The new reflectometer consists of a hollow sphere, with a segment of the surface cut off. It is painted white inside, and light is projected through a small hole in the wall onto the sphere wall, or onto the test surface over the opening. It can be adapted to use with any good type of portable photometer, and will give absolute, not relative, reflection factors.

The instrument has been checked by measurements by an independent method, and was found to give correct results when used as recommended.

Magnesium carbonate has usually been used as the standard when measuring reflection factors by several laboratory methods, the assigned value being 88 per cent. Measurements by four absolute methods showed that the factor was approximately 99 per cent. for one block, and 98 per cent. for another.

The paper gives a complete description of the theory and tests of the new instrument, as well as a description of the various reflectometers which have been used in the past.

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[3] Scientific Paper No. 391.

AUTOMATIC APPARATUS FOR INTERMITTENT TESTING.[4]

By G. W. Vinal and L. M. Ritchie.

[ABSTRACT]

This apparatus has been devised to meet the needs of the Bureau of Standards in making tests of dry cells and storage batteries, but is applicable to nearly any form of intermittent testing requiring the closing of electrical circuits at regular time intervals. The particular advantages of this type of apparatus for making these tests are: (1) elimination of rapidly-moving parts; (2) accuracy of the time intervals; (3) possibility of making a number of different tests simultaneously with the same apparatus.

RELATIVE SPECTRAL TRANSMISSION OF THE ATMOSPHERE.[5]

By Dr. E. Karrer and E. P. Tyndall.

[ABSTRACT]

Data on the transmission of light by the atmosphere are essential in order to compare various searchlight beams whose characteristics are invariably obtained at different times and under different atmospheric conditions; and are also essential in all considerations as to what the color of a searchlight beam should be to obtain best results. For these latter considerations the relative spectral transmission of the atmosphere is required. Not only are such data on the spectral transmission of the atmosphere of value to the theory and practice of searchlight illumination but are also of prime importance to an intelligent consideration of headlamps for automobiles and locomotives, as well as to the selection and development of color schemes and emulsions for use in aerial photography.

The method consisted in comparing, wave length for wave length, the intensity of a ray of light emitted by an incandescent lamp, after reflection from a mirror 600 mμ distant with that of a ray directly entering the spectrophotometer near the lamp. Either of these rays could be allowed to enter one of the collimators of a Brace spectrophotometer, to be compared alternately

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[4] Technologic Paper No. 171.
[5] Scientific Paper No. 389.

in intensity with a beam from the same incandescent lamp entering the second collimator. The photometric balance was obtained by varying the slit width of this second collimator admitting the comparison beam.

Data on the relative spectral transmission are given, (1) for a clear atmosphere, (2) for the atmosphere of high humidity, and (3) during rains. The curves for (1) show little selectivity. Between wave lengths 520 and 660 mμ the transmission is uniform. At 660 it begins to decrease. Also from 520 to 440 mμ it gradually and continuously decreases. The curves for the atmospheric condition of (2) and (3)' are almost identical for the region from 430 to 560 mμ, the transmission increasing with the wave length. In the region from 560 to 670 mμ the curve for the rainy atmosphere shows a maximum near 640 mμ, while that for the atmosphere of high humidity indicates two maxima, at 580 and at 650 mμ, with a minimum near 620 mμ. The decrease at 660 mμ in both cases is very similar to that noted for the clear atmosphere, and is probably to be associated with the absorption band of the oxygen of the atmosphere.

The data show that under weather conditions such as prevailed during the experiments the light in the orange region of the spectrum will be transmitted by the atmosphere with least relative depletion. In applying these data, however, due consideration must be made of other factors that are of importance to good seeing under various conditions of illumination.

THE TWO COMMON FAILURES OF THE CLARK STANDARD CELL.[6]

By E. C. McKelvy and M. P. Shoemaker.

[ABSTRACT]

THE International Electrical Congress of 1893 adopted the Clark cell as the international standard of electromotive force. In 1908 The International Conference on Electrical Units and Standards selected the Weston Normal Cell as the more satisfactory standard. One of the chief factors influencing this change was the large percentage of failures of Clark cells through cracking of the cell wall about the sealed-in negative terminal, and through the formation of gas in the amalgan limb.

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[6] Scientific Paper No. 390.

It is shown that the cracking of the cell can be prevented by sealing into the cell wall for the negative terminal platinum wire previously subjected to the action of zinc amalgam, and that the effects of the formation of gas can be minimized through the employment of the smallest excess of crystals required to insure saturation at the highest temperature at which the cell is likely to be used.

PHOTOGRAPHIC METHOD OF DETECTING CHANGES IN A COMPLICATED GROUP OF OBJECTS.[1]

By M. H. Stillman.

[ABSTRACT.]

A NEGATIVE is made of the group of objects in which a change is expected. After the change is supposed to have occurred, a second negative of approximately the same density as the first is made with the same camera (or one of the same kind) on a plate of the same kind and from as nearly as possible the same position as used in making the first negative. A positive is printed from one of the negatives, is superposed upon the other negative so as to bring them into register, and the combination viewed against a source of light. When the photographs are properly made, those parts of the combination which correspond to the unchanged portion of the group of objects, will appear as a field of practically uniform density, while a change in the group will be revealed by a considerable departure from this uniform density.

It is very desirable to make the negatives and positive of considerable contrast and at the same time confine all exposures to the straight-line portions of the characteristic curves. To secure the best results the positive should have a contrast equal to the ratio of the contrast of the negative superposed upon the positive to the contrast of the negative from which the positive is derived.

The method has for some time been used to a limited extent in astronomy and physics. It was independently devised by the present author about three years ago and developed for camouflage detection, engineering and other purposes in coöperation with Dr. H. E. Ives of the United States Air Service.

[1] Scientific Paper No. 392.

NOTES FROM NELA RESEARCH LABORATORY.*

Nela Research Laboratory was organized in 1908 under the Directorship of Dr. Edward P. Hyde as The Physical Laboratory of the National Electric Lamp Association. The name was changed to Nela Research Laboratory in 1913, when the National Electric Lamp Association became the National Lamp Works of General Electric Company. For some years the Laboratory was devoted exclusively to the development of those sciences on which the art of lighting has its foundation, but in 1914 the functions of the Laboratory were extended by the addition of a small Section of Applied Science, which had an immediate practical objective.

The Section of Applied Science is now being largely extended as a separate Laboratory of Applied Science under the immediate direction of Mr. M. Luckiesh, who becomes Director of Applied Science, and a new building is being constructed to house this branch of the work, which will be carried forward with a staff of several physicists, an engineer, an architect and a designer, together with the necessary technical and clerical assistants.

Dr. Ernest Fox Nichols, formerly President of Dartmouth College, and more recently Professor of Physics at Yale University, has accepted an invitation to assume the immediate direction of the Laboratory of Pure Science, under the title of Director of Pure Science. The work of this Laboratory, which will be continued in the present building, will be somewhat further extended under the new organization.

The Laboratory of Pure Science and the Laboratory of Applied Science will together constitute the Nela Research Laboratories, and will be coördinated under the general direction of Doctor Hyde, who becomes Director of Research.

* Communicated by the Director.

Decolorizing Carbon.—While finely divided carbon has been used to decolorize solutions, but little study has been made of its action in the removal of other substances from their solutions. JOSEPH C. BOCK, of Marquette University (*Journal of the American Chemical Society*, 1920, xlii, 1564–1569), has investigated the properties of " Norit," a finely divided vegetable carbon. Most of the experiments were made on urine; a 100 c.c. sample of urine was shaken with Norit, of which 5 grams were usually, though not invariably, used. The shaking was not of necessity very prolonged or especially vigorous; the requisites were good mixing, and an even distribution of the Norit throughout the liquid. From the urine Norite removed: Ammonia, glucose, and chlorides slightly; urea, total nitrogen, and phosphates to a considerable extent; creatinine very largely; uric acid completely. The adsorption of these solids from their solution in the urine by the Norit was specific and selective. When several solutes were present in a solution, each of them was adsorbed by Norit to a lesser extent than when present separately. Norit decreased the bacterial count of bouillon cultures, but did not produce sterility. The adsorptive power of Norit was somewhat increased by successive treatment with dilute hydrochloric acid water, dilute alkali, and, finally, washing until neutral in reaction.

J. S. H.

Response of Cottonseed Oil Products to the Kreis Test for Rancidity.—In the Kreis test a fat or oil is shaken with equal volumes of hydrochloric acid and a solution of phloroglucinol in ether. The development of a red color indicates that the fat or oil is rancid; its formation is probably due to the presence of aldehydes or ketones in the material tested. Chromogenetic substances, which give a positive Kreis reaction, occur in crude cottonseed oil. The researches of W. B. SMITH (*Journal of Industrial and Engineering Chemistry*, 1920, xii, 764–766) show that refined cottonseed oils and their products at times contain these chromogenetic substances, carried over from the crude oil. These substances sometimes cause a positive Kreis reaction by a nonrancid oil; and hence the value of the positive Kreis test as evidence of rancidity is greatly lessened in the case of cottonseed oil.

J. S. H.

The World's Rainfall. (*U. S. Geol. Surv. Press Bull. No. 452*, July-August, 1920.)—The total annual rainfall upon all the land of the globe amounts to 29,347 cubic miles, and of this quantity 6524 cubic miles drains off through rivers to the sea. A cubic mile of river water weighs about 4,205,650,000 tons and carries in solution an average of about 420,000 tons of foreign matter. In all, about 2,735,000,000 tons of solid matter is thus carried annually to the ocean.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

SEDOHEPTOSE, A NEW SUGAR FROM SEDIUM SPECTABILE II.[1]

By F. B. La Forge.

[ABSTRACT]

SEDOHEPTOSE was discovered in the leaves and stems of sedum spectabile, a cultivated plant commonly used for ornamental purposes. The sugar was isolated and characterized as ketose, after which a number of derivatives were prepared as described in a previous article.[2]

Upon reduction of sedoheptose with sodium amalgam, two heptitols, one active and one inactive, were formed. The active (a) sedoheptitol has the configuration,

$$
\begin{array}{ccccccc}
H_2 & H & H & H & H & H & H_2 \\
& & & & & & O \\
C - & C - & C - & C - & C - & C - & C \\
O & O & O & O & O & H & O \\
H & H & H & H & H & & H \\
\end{array}
$$
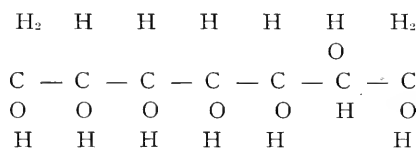
There are two possibilities with respect to the configuration of the inactive sedoheptitol (β),

$$
\begin{array}{ccccccc}
H_2 & H & H & H & H & H & H_2 \\
& & & & & & \\
C - & C - & C - & C - & C - & C - & C \\
O & O & O & O & O & O & O \\
H & H & H & H & H & H & H \\
\end{array}
\qquad
\begin{array}{ccccccc}
H_2 & H & H & H & H & H & H_2 \\
& & O & & & & O \\
C - & C - & C - & C - & C - & C - & C \\
O & & O & O & O & & O \\
H & H & H & H & H & H & H \\
\end{array}
$$

and
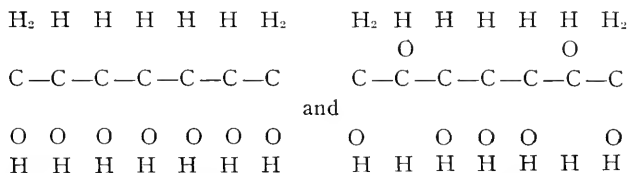
Sedoheptose is shown to be an alpha ketose to which one of the two possible formulas,

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* Communicated by the Chief of the Bureau.
[1] Published in *J. Biol. Chem.*, **42** (1920), 367.
[2] Published in *J. Biol. Chem.*, **30** (1917), 61.

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H₂  H   H   H   H        H₂        H₂  H   H   H   H   ·    H₂
    O
C —C —C —C —C —C —C           C —C —C —C —C —C —C
                    or
O       O   O   O   O   O        O   O   O   O   O   O   O
H   H   H   H   H       H        H   H   H   H   H       H
```
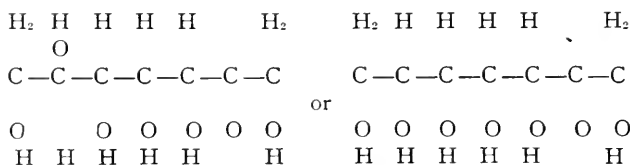
must be assigned.

This point can be decided when the active and one of the two inactive heptitols resulting from its reduction are prepared from heptoses of known configuration.

VOLEMITE.[3]

By F. B. La Forge.

[ABSTRACT]

The natural heptitol volemite described by Bourquelot and Fischer was shown in a previous article [4] to be very similar in properties to α sedoheptitol obtained from sedoheptose by reduction.

A sample of natural volemite obtained later was found to correspond in all its properties with α sedoheptitol. In addition to other derivatives of sedoheptitol already described, its acetal was prepared by condensation with acetaldehyde. This compound showed $[α]_D$ in chloroform solution $= -45.55$ which agreed with the rotation given for volemite acetal by Bougault and Allard.[5] The melting points of the two heptitols were identical and the mixed melting point showed no depression. As the formula

```
H₂   H    H    H    H    H    H₂
                              O
C  — C  — C  — C  — C  — C  — C      or its
O    O    O    O    O         O
H    H    H    H    H    H    H
```
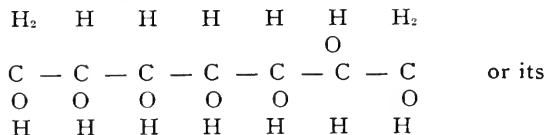
mirror image as shown in the article must be the formula for sedoheptose, this must also be the one which corresponds to volemite.

ᵃPublished in *J. Biol. Chem.*, **42** (1920), 375.

⁴ *J. Biol. Chem.*, **30** (1917), 61.

⁵ *Compt. rend.*, **135** (1902), 796.

THE ODOROUS CONSTITUENTS OF APPLES. EMANATION OF ACETALDEHYDE FROM RIPE FRUIT.[6]

By Frederick B. Power and Victor K. Chestnut.

[ABSTRACT]

No information of a definite nature has hitherto been recorded with respect to the odorous constituents of apples, and although preparations designated as " apple oil " or " apple essence " have long been in use, these have consisted entirely of artificial products. Moreover, many of the components of such preparations are now known not to be contained in the apple, and some of them do not even occur in nature.

In order to elucidate the subject, a complete investigation was undertaken in the Bureau of Chemistry of the United States Department of Agriculture, as a result of which the following facts have been established :

1. The odorous constituents of apples consist essentially of the amyl esters of formic, acetic, and caproic acids, together with a small amount of the caprylic ester and a considerable proportion of acetaldehyde.

2. Acetaldehyde is a product of the vital activity of the fruit, and occurs in the exhalation from ripe apples.

3. In addition to the substances mentioned in paragraph 1, the aqueous distillate from fresh apple parings contains exceedingly small amounts of methyl and ethyl alcohols as well as a little furfural. As the last-mentioned compound is only produced during the process of distillation, it does not represent an odorous constituent of the fruit.

4. The essential oil from apples is at ordinary temperatures a yellowish, somewhat viscid liquid, which becomes darker on keeping. When slightly cooled, it forms a concrete mass, due to the separation of small acicular crystals which consist of a paraffin hydrocarbon. It possesses in a high degree the characteristic fragrant odor of fresh apples. Besides the esters mentioned, it contains small amounts of acetaldehyde and furfural. The yield of oil from the parings of the Ben Davis apple was 0.0035 per cent., and that from the more odorous crab-apple

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[6] Published in *J. Am. Chem. Soc.*, **42** (1920), 1509.

0.0043 per cent., representing 0.0007 and 0.0013 per cent., respectively, of the entire fruit.

5. Although in chemical literature amyl valerate is generally designated as " apple oil," it is quite certain that this compound has never been found in the apple, and in the recent investigation no evidence could be obtained of its presence. On the other hand, the characteristic, fragrant odor of ripe apples has now been shown to be due to a combination of the substances enumerated above. These substances may exist in varying proportions in the numerous varieties of the fruit, thus causing slight differences in odor.

Starch Content of Silage.—Arthur W. Dox and Lester Yoder (*Journal of Agricultural Research*, 1920, xix, 173–179) made chemical analyses of corn silage at various stages of its fermentation. The fermentation was normal with respect to development of aroma and changes in acidity, alcohol, and sugar content; these changes were entirely independent of the starch content of the ensiled corn and of the silage produced from it. The first intermediate products, which form in the decomposition of starch, *i.e.*, soluble starch and dextrins, were never present in demonstrable quantities; and the starch content remained constant throughout the process of fermentation. The starch granules remained intact, and underwent no change which could be detected by microscopic examination. " Since starch constitutes about 10 per cent. of the corn plant at the time of ensiling and represents over 400 calories of available energy per kilogram, the fact that no loss occurs during fermentation is an additional argument in favor of silage as an economical feed."

J. S. H.

Melting Points and Thermoelectric Behavior of Lead Isotopes.—Theodore W. Richards and Norris F. Hall, of Harvard University (*Journal of the American Chemical Society*, 1920, xlii, 1550–1556), used two isotopes—ordinary lead and Australian radioactive lead—in their research. While the two isotopes differed in atomic weight by 0.8, the difference in their melting points, if appreciable, did not exceed 0.05° C. " It is fairly safe to assume that the kinds of lead not only have very nearly the same melting point, but also (since the sample consisting chiefly of the lighter isotope doubtless contained ordinary lead) they mix (or rather mutually dissolve) without affecting the melting point." The Seebeck thermoelectric effect produced at a junction of the two isotopes was shown to be *nil*.

J. S. H.

NOTES FROM THE U. S. BUREAU OF MINES.*

INDICATORS FOR CARBON DIOXIDE AND OXYGEN IN AIR AND FLUE GAS.

By L. H. Milligan.

THERE is a distinct need for simple, compact, portable instruments that will indicate quantitatively the proportions of CO_2 and of oxygen in air that people who work in confined places must breathe, and also the CO_2 content in flue gases.

Apart from the presence of toxic gases like CO, the greatest danger to men working in inclosed places comes chiefly from an increase in CO_2 or decrease in oxygen content of the air breathed. These conditions generally accompany each other, as processes of organic oxidation, such as fires, breathing of men, surface oxidation of coal in a coal mine, convert the oxygen of the air into CO_2. When a man breathes air containing more than 2 per cent. CO_2 for any considerable period, his working efficiency is reduced, and he is in considerable danger when the air contains more than 4 per cent. CO_2 or less than 13 per cent. oxygen. Instruments with which CO_2 and oxygen can be determined will give warning of danger in time to avert it.

Fuel is burned most efficiently when the oxidation is complete, and in burning coal, coke, petroleum, natural gas, or other fuels, this condition is most nearly met when the flue gases have a high CO_2 content. Therefore, one method of maintaining high efficiency in a power plant is to make frequent determination of the CO_2 in the flue gases.

In the laboratory, air or gas analyses are made with stationary apparatus, but in the field portable types must be used. Various portable devices have been designed and marketed, but in general they have been bulky, heavy, more or less fragile, and require a trained chemist to operate them.

The Bureau of Mines, with a view to overcoming these objections, has developed three types of portable indicators in its chemical research laboratory at the Pittsburgh station, one for deter-

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mining the CO_2 content in the air, one for determining CO_2 in flue gases, and one for determining oxygen in air. These are described in Technical Paper 238, " Indicators for Carbon Dioxide and Oxygen in Air and Flue Gas," by L. H. Milligan, D. O. Crites, and W. S. Wilson.

DETERMINATION OF MOLYBDENUM.

By J. P. Bornardi and E. P. Barrett.

During the recent activity in the molybdenum market, the methods that have been used for the determination of molybdenum were found inadequate. They were satisfactory for small tonnages of high-grade material, but with the introduction of flotation and the demand caused by the war, the tonnage became so large and the grade of products so low that determination of Mo to the second decimal place was necessary.

The Bureau of Mines, in an investigation recently concluded, has developed improved methods of both volumetric and gravimetric analysis, that are more rapid and accurate than any previously devised.

Among quantitative methods for the determination of molybdenum that are in general use, that of reduction of the molybdenum and titration with potassium permanganate proved to be the most promising and a technic was worked out by which it is satisfactory for rapid, accurate determinations on low-grade ores. In this method the ore is decomposed either by acid or by fusion with Na_2O_2 into a soluble molybdate and insoluble compounds of the other constituents of the ore. The molybdate is filtered, acid added, and the solution is passed through a Jones reductor where the MoO_3 is reduced to Mo_2O_3. The Mo_2O_3 is then titrated with $KMnO_4$, and the percentage of molybdenum present is calculated. Successful use of the method, however, requires close attention to details of procedure.

Gravimetric determination of molybdenum by precipitating and weighing as lead molybdate proved to be rapid and accurate, although certain precautions must be observed. In this method the ore is decomposed with acids and treated with ammonium hydroxide to form ammonium molybdate. From the hot solution the molybdenum is precipitated as $PbMoO_4$ by adding lead acetate solution in 2 or 3 c.c. excess, heating the mixture a few minutes,

and filtering. The precipitated lead molybdate is then ignited, cooled, weighed, and the weight of molybdenum is calculated. Technical Paper 230, of the Bureau, gives details of the methods.

THE PROPERTIES OF STONEWARE CLAYS.

By H. G. Schurecht.

Experiments have been conducted by the Bureau of Mines at its ceramic station, at Columbus, Ohio, on the properties of some Ohio and Pennsylvania stoneware clays, with special reference to the possible use of these clays in making chemical stoneware. This work, described in Technical Paper 233 of the Bureau of Mines, was conducted in coöperation with the Ohio Geological Survey, and the Pennsylvania Geological Survey.

From each of the eleven clays tested, a series of seven bodies were prepared, the clay being ground to different grades of fineness and used alone and with varying proportions of feldspar, or feldspar and calcium carbonate added. From those bodies test pieces were prepared which were tested for their pyro-physical properties. The results show a wide range of properties among the different clays tested, and indicate that some of the clays might be used for chemical stoneware.

CASING TROUBLES AND FISHING METHODS.

By Thomas Curtin.

The Bureau of Mines has completed an investigation of casing troubles and fishing methods in oil wells. In the past, many wells have been abandoned because of casing troubles that were thought to be insurmountable, whereas these troubles could have been overcome, had the operator been better informed as to practices and methods employed in other fields, with which he was not familiar. In fields where casing difficulties are of daily occurrence, methods for combatting them have been developed, and if these methods were more widely known and applied wherever the same conditions exist, the oil industry would be greatly benefited. Bulletin 182, of the Bureau of Mines, which presents the results of the investigation, attempts to classify these troubles and suggests solutions that will save the operator discouragement and expense.

Wire Mesh Army Roads in Egypt. T. McLEAN JASPER. (*Engineering News Record*, August 12, 1920, p. 302.)—Loose sand, smoothed and levelled and then covered with chicken netting, firmly pegged down, made roads which gave such good service during the British Army operations in Egypt and Palestine that the method of construction appears to offer possibilities for temporary roads for construction and engineering operations where travel over sand is necessary.

As laid down by the army troops, the best results were obtained with chicken netting of about ¾ in. mesh. This netting, 2½ or 3 ft. wide, came in rolls and four or five rolls placed end to end were unrolled along the route so as to cover a strip about 12 or 15 ft. wide. The joining edges of the netting were fastened together either by clipping on loops of wire at about 3 ft. intervals or by a continuous wire woven in and out of the two edges. At intervals of about 5 ft. the outside edges were pegged down with 1½ in. stakes from 12 to 18 in. long. Roads so constructed were perfectly satisfactory for infantry but were badly damaged if horses or cars were driven over them. The life of these roads is difficult to state; one which had been marched over daily by 3000 to 4000 men was in good condition after six months' use. Other roads, however, failed quite soon. The grade is levelled and smoothed before the netting is laid. No hollows should be left under the netting and the netting should be securely pegged down. As ruts form, the netting is lifted and the sand relevelled. The netting lasts from three to six months, depending on the volume of traffic. Roads of this type are of use only for mechanical transport with pneumatic tires; horse and wheel transport destroy them almost at once.

Castor Oil. (*Engineering World*, August, 1920, p. 100.)—Castor oil figures to a large extent in the manufacture of the artificial leather which takes the place of natural leather in upholstery. It is also an essential component in some artificial rubbers and various kinds of celluloid. The oil furnishes a coloring for butter, and from it is produced the so-called "Turkey red" oil which is an important factor in the dyeing of cotton textiles. One of the largest uses of castor oil is in the making of transparent soaps. The oil also yields sebacic acid, which is employed in the manufacture of candles, and from it is also obtained caprylic acid, which enters into the composition of varnishes peculiarly suitable for the polishing of all kinds of high-class furniture and of carriage bodies. Castor oil is also used in the making of certain waterproof preparations. Most fly-papers owe a large part of their instantaneous action and effectiveness to the fact that the preparation smeared on them largely consists of castor oil.

THE FRANKLIN INSTITUTE.

MEMBERSHIP NOTES.

CHANGES OF ADDRESS.

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Mr. H. Goodwin, Jr., Superpower Survey, 708 Sixth Avenue, New York, New York.

Mr. George W. Lewis, National Advisory Committee for Aeronautics, 2722 Navy Building, Washington, D. C.

Mr. Robert B. Lewis, 51 East Penn Street, Germantown, Philadelphia, Pennsylvania.

Dr. W. F. Rittman, Alpena, Michigan.

Mr. Frederick W. Salmon, 274 Wellington Avenue (Auburn), Providence, Rhode Island.

Mr. Lewis K. Sillcox, 7249 Carlisle Avenue, Chicago, Illinois.

Dr. C. C. Thomas, Dwight P. Robinson & Company, Electric Equipment Building, 1240 South Hope Street, Los Angeles, California.

Mr. John C. Trautwine, 3d., Box 6509, Upper Darby Branch, Philadelphia, Pennsylvania.

NECROLOGY.

Mr. A. R. Shipley, 186 Canner Street, New Haven, Connecticut.

Albert R. Shipley was born at Alpha, Maryland, in 1876, and died in February, 1920. He attended school in Baltimore and later graduated from the McDonough Institute and the Maryland Institute. He was connected with numerous industrial establishments in varous capacities from machinist to engineer. During the Spanish-American War he served as Machinist's Mate and Engineer in the Navy. In 1916 he was called by the Government to the Watertown Arsenal to become Superintendent of Production and continued in this position for sixteen months. The last years of his life he spent as industrial engineer and production superintendent.

Mr. Shipley was a member of the American Society of Mechanical Engineers, the Taylor Society and various other organizations. He contributed papers to the technical societies with which he was connected and frequently took part in discussions. He became acquainted with Mr. Frederick W. Taylor during his connection with the Tabor Manufacturing Company and took a great interest in scientific management; he was recognized as an authority and occasionally delivered lectures on the subject.

Mr. Shipley became a member of the Institute on March, 12, 1913.

Dr. Isham Randolph, 1827 Continental & Commercial National Bank Building, Chicago, Illinois.

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BOOK NOTICES.

MÉMOIRES SUR LA RESPIRATION ET LA TRANSPIRATION DES ANIMAUX. Par Antoine-Laurent Lavoisier. 12mo, 68 pages, Gauthier-Villars et cie. 3 fr. in paper.

OBSERVATIONS ET EXPÉRIENCES FAITES SUR LES ANIMALCULES DES INFUSIONS, Par Lazare Spallanzani. Two parts, 12mo, 105 and 122 pages, respectively. Gauthier-Villars et cie. 3 fr. each in paper.

These are two volumes of the series of " *Les Maîtres de la Pensée Scientifique* " that the well-known Paris publishing house is issuing, the general

nature of which series was indicated in a review of the first volume. Lavoisier's essay was, of course, originally written in French, so the present issue is merely reprinted from the original memoir, but Spallanzani's memoir was written in Italian, the French text herewith presented being that by Jean Senebier published at Geneva in 1786.

Both essays are interesting. Lavoisier's memoir is well-known to all chemists who have taken interest in the history of the science, as one of epoch-making type, for in it he describes the experiments of heating mercury for a long while in a closed vessel containing air, by which he proved that the formation of the " calx " was due to a direct absorption of a portion of the air, the remaining portion being incapable of supporting combustion of life and being without action on nitric oxide.

Spallanzani's essay is of interest rather to biologists than chemists, but gives a striking picture of the early struggle concerning the nature of generation and reproduction. It is not easy to see why it was divided into two small volumes. It would be an excellent book for a young biologist who has just acquired a reading knowledge of French, for it is written in a very clear style.

Henry Leffmann.

A History of Chemistry from the Earliest Times. By the late James Campbell Brown, D.Sc. (London) LL.D. (Aberdeen). Second edition, edited by Henry Hilton Brown, 8vo. 538 pages, contents, index, portrait and one hundred and six illustrations. Philadelphia, P. Blakiston's Son & Co,, 1920.

Histories of chemistry carry us back to a very remote period in human civilization. Modern writers of such works are guided largely by the plan of the great classic in the field, Kopp's " Geschichte der Chemie," now about three-quarters of a century old, but still as important to the student of the subject as is Gibbons' " Decline and Fall " to the student of the history of Europe. Brown follows, substantially, Kopp's system, which divides the early history of chemistry into four periods. Present-day historians are not as strongly inclined to mark off periods as sharply as formerly, regarding the course of events as almost insensibly progressive and not catastrophic.

We are informed in the preface of this edition that it is, except in a few places, a reprint of the first. While it is true that but a little of new has been brought forward in the seven years that have elapsed since the publication of the first edition, it is doubtful if the desire " To preserve Dr. Brown's work as nearly as possible in the shape he wished it to take " is the best service that an editor can render.

So far as the matter of the book is concerned, it is only necessary to say that it is a compact, carefully written and comprehensive account of the history of the science from the earliest recorded date down to a recent period. Some of the most important developments of physical chemistry are left untouched, and the "phase rule" is not found in the index. The style of the text is lively and not infrequently the reader is entertained with a humorous observation. Out of curiosity the reviewer turned to the reference to helium

to see if the author had fallen into one of the numerous pitfalls that seem to beset that element. Sure enough, a glaring error is noted. It is stated (p. 524) that Janssen gave the name to the element causing the peculiar yellow line in the spectrum of the sun's chromosphere! One would suppose that no Englishman would be capable of taking from Lockyer the honor of coining the accepted name for this now famous element.

HENRY LEFFMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS. The Limiting Velocity in Falling From a Great Height. Report No. 78, Preprint from Fifth Annual Report. 8 pages, quarto. Washington: Government Printing Office, 1920.

This report, by Professor E. B. Wilson, deals with the velocity in falling bombs when the variation in air density with height is taken into account. It is shown that bombs must be dropped from considerable altitudes in order that they may reach a maximum velocity before striking the ground.

Report No. 79. Bomb Trajectories. Preprint from Fifth Annual Report. 10 pages, quarto. Washington: Government Printing Office, 1920.

This report is a mathematical discussion of the trajectories of bombs or projectiles when account is taken of the resistance of the air. It is impossible to express the motion of the bomb exactly so that it must be approximated between two limiting curves whose equation can be expressed. It is found that the trajectory in ordinary cases is not far from a parabola, and with an initial velocity of 200 feet per second and a terminal velocity of 800 feet per second in a drop of 2000 feet the correction can be determined to within 15 feet.

Report No. 81. Comparison of U. S. and British Standard Pitot-Static Tubes. Preprint from Fifth Annual Report. 8 pages, plate, quarto. Washington: Government Office, 1920.

British and United States standard Pitot tubes were placed in the reduced section of the Navy Yard 8 foot tunnel and the heads for each tube were determined for speeds from 20 to 160 miles per hour. In order to be sure that the velocity was the same at the positions at which the Pitot-Static tubes were placed, after the first run the position of the tubes was reversed and a second run made. It was found that the two tubes checked with one another within the precision of the measurements and gave a true Pitot reading.

Report No. 86. Properties of Special Types of Radiators. 16 pages, ilustrations, plates, quarto. Washington: Government Printing Office, 1920.

The report discusses the general performance characteristics of three special classes of radiators: Those with flat-plate water tubes, fin and tube types and types that whistle in an air stream. Curves and tables show the performance of representative radiators of each class, and compare the flat plate and whistling types. Empirical equations are given for estimating the performance of flat-plate radiators of various dimensions.

The report also contains a brief discussion, with curves showing effect of yawing on the properties of a radiator.

PUBLICATIONS RECEIVED.

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Motion Study for the Handicapped, by Frank B. Gilbrith and Lillian Moller Gilbrith, Ph.D. 165 pages, illustrations, plates, 8vo. London, George Routledge and Sons, Ltd., 1920. New York, E. P. Dutton & Company. Price, $4 net.

National Conference on Concrete House Construction: Proceedings held at Auditorium Hotel, Chicago, February 17, 18, and 19, 1920, edited by the Secretary, 235 pages, illustrations, 8vo. Chicago, Published by the Conference, 1920.

Bureau of Standards: Circular No. 92, Operation and Care of Vehicletype Batteries, 94 pages, illustrations, plates, diagrams, 8vo. Washington, Government Printing Office, 1920. Price, 30 cents.

Bureau of Mines: Bulletin 173, Manganese Uses, Preparations, Mine Costs, and the Production of Ferro-alloys, by C. M. Weld and others. 209 pages, 8vo. Technical Paper 229. Accident Prevention in the Mines of Butte, Montana. 59 pages, plate, 8vo. Technical Paper 244, Use of Stenches as a Warning in Mines, by S. H. Katz, V. C. Allison, and W. L. Egey. 31 pages, illustrations, plate, 8vo. Washington, Government Printing Office, 1920.

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National Advisory Committee for Aeronautics: Technical Notes No. 8, Duralumin, by E. Unger and E. Schmidt, translated from *Technische Berichte,* vol. iii, Section 6, by Starr Truscott, 10 pages, plates. No. 9, Theory of Lifting Surfaces, Part I, by L. Prandtl, translated from the German and abstracted by W. Margoulis, 11 pages. No. 10, Theory of Lifting Surfaces, Part II, by L. Prandtl, translated from the German and abstracted by W. Margoulis, 10 pages. Three pamphlets, quarto. Washington Committee, 1920.

CURRENT TOPICS.

Standardized Lumber Sizes Means. (*U. S. Forest Products Laboratory, News Note.*)—The need of standard sizes for all the different lumber products has been felt for some time and the action of prominent lumbermen in promoting standardization presages another progressive step in the lumber industry. The laboratory has been coöperating during the past year with the National Lumber Manufacturer's Association in working out an equitable basis for standardizing softwood lumber sizes. Some of the benefits to be derived from the standardization of sizes are as follows:

1. It makes possible a common language for all. The consumer can substitute one species for another with assurance of getting material of the same size. Similarly, if a contractor starts to build several houses and orders his millwork, sash, doors, etc., based on certain lumber sizes as to stock around which the casing fits, the kind of wood can be varied as he desires.

2. Architects and purchasers can order more rapidly with one set sizes.

3. Material of standard sizes is more salable.

4. Building design is simplified, since fewer sizes can be used.

5. Uniformity in construction results, regardless of the grading rules under which the material is purchased.

6. Remanufacture of larger sizes to match smaller sizes will be reduced and greater utilization with less labor and expense result.

7. Standardization of sizes eliminates local legislation on lumber sizes which confuse manufacture and distribution. Such legislation has been already suggested.

8. Standardization makes for fewer sizes and hence greater efficiency, ease and accuracy in lumber grading.

9. It equalizes competition between manufacturers, because present-differences in overrun and freight charges are important factors in determining price.

10. It makes possible uniform practice and sizes in resawing.

11. It makes possible a fewer number of drying schedules in the kiln drying of lumber.

The National Lumber Manufacturer's Association will meet September 28th and 29th in Chicago, at which time action will be taken on the standardization of sizes for all softwood lumber.

Pulp and Paper Manufacture. (*U. S. Forest Products Laboratory, News Note.*)—There are four general processes of reducing wood to a pulp condition. They are known as the ground wood, sulphite, sulphate and soda processes of pulping.

The ground wood process of pulping is used mainly for the

reduction of non-resinous, long-fibred woods, such as spruce and balsam. The barked wood in 2-foot lengths is ground on a grindstone, the surface of which has been sharpened to produce a cutting action. The yield of pulp is approximately 90 per cent. of the weight of the raw wood. The pulp is inferior in quality and is used only to mix with longer- and stronger-fibred stock—such as unbleached sulphite pulp—in the manufacture of paper in which permanency is not required.

The sulphite process is used chiefly for the reduction of long-fibred, non-resinous, coniferous woods, such as spruce, balsam and hemlock, giving a yield of less than 45 per cent., based on the weight of the original wood used. This pulp can be bleached to a high degree of white and is largely used both unbleached and bleached in the manufacture of books, newsprint, wrapping, bond, and tissue papers.

The sulphate or kraft process of pulping is used for the reduction of any long-fibred wood and yields approximately 45 per cent. This is an alkaline process and can be used for the reduction of both resinous and non-resinous woods, such as the pines, spruces, hemlocks, firs, etc. Kraft pulp is normally not bleached; but on account of its strength it is used for the manufacture of kraft wrapping paper and high test container board.

The soda process is restricted in use to the short-fibred deciduous woods, such as aspen, cottonwood, willow, gum woods, etc., yielding less than 45 per cent. The resulting pulp is invariably bleached to a high degree of white, and after admixture with a longer- and stronger-fibred stock, such as spruce sulphite, is used for the manufacture of book, lithograph, envelope papers, etc.

Mountains in Idaho. (*U. S. Geol. Survey Press Bulletin No. 454,* August, 1920.)—Hyndman Peak is the only named mountain in Idaho that rises above 12,000 feet. It stands near the Blaine–Custer county line and has a height of 12,078 feet. There are, however, several unnamed peaks near Hyndman Peak whose elevations are greater than 12,000 feet, as shown by the contours on the Hailey topographic map, published by the Survey.

Highest Mountain of Guam. (*U. S. Geol. Survey Press Bulletin No. 454,* August, 1920).—Guam, our little Pacific Island possession, is a mere speck in the " South Sea," as Balboa called the Pacific Ocean, but it is by no means flat. Jumulong Mangloc, the highest point in the island, stands 1,274 feet above the sea, according to a chart published by the Survey.

OPTICAL GLASS AND ITS FUTURE AS AN AMERICAN INDUSTRY.*

BY

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THE problem of preparation for a war in which the scope of its technique and the wealth of the available resources are both practically unlimited, will hardly be comprehended at a glance by anyone, whatever his previous training may have been. It is an absolutely baffling task. By way of illustration consider artillery fire, which during the Civil War was practically always point blank; that is, aim was taken directly at a nearby object, either in plain view or partially concealed by smoke. The effective range was rarely more than 3000 yards, and the pieces were pointed by instinct or by sighting along the barrel, but none of the present day equipment for ascertaining the range of very distant objects was then thought of. Few of the guns were rifled at all, high-power explosives had not been discovered, muzzle loading by hand was nearly universal, and except for the old-fashioned siege mortars high angle fire was not attempted.

The artillery practice of the present war included, as will be recalled, the remarkable achievement of bombarding the city of Paris from a distance of about 72 miles. Moreover, in the regular daily artillery battles naval guns were frequently concentrated to "cover" an opposing battery which might be distant ten miles or more, perhaps be completely concealed by intervening hills or trees, and which sometimes occupied no more space than an area 50 or 60 yards square. Moreover, it is told of this kind of fire that it frequently was so successfully concentrated that such batteries were completely wiped out by a single avalanche of high-explosive shell.

Artillery practice of this character necessarily requires instruments of the highest precision and of complicated mechanism which are capable of adjustment for nearly all variations of service conditions including allowance for atmospheric changes high above the earth. It is thus easy to see that not only must a high degree of mechanical skill be worked out in advance to provide this technique, but the glass of which the optical parts of the instruments are made must be of the highest perfection in order not to vitiate this technique when developed.

The problem of supplying optical glass in adequate quantity and perfection was therefore one of the most serious problems confronting the ordnance departments from the first moment when our entry into the war was seriously considered. There is no possibility of accurate fire control without optical glass.

At the end of March, 1917, a committee was appointed from the Naval Consulting Board to inquire into the supply of optical glass of quality suitable for fire control instruments for the use of the military and naval forces of the United States in the event of our participation in the war. This is the first action of record, so far as I am aware, to obtain a supply of this absolutely indispensable material.

The situation may well have been deemed precarious, for the reason that at that time the European war had been going on for nearly three years and the available supply of imported glass in the hands of American manufacturers had become seriously depleted in filling contracts with various allied powers. In point of fact, substantially all of the optical glass of the first quality on hand in this country in 1914 had been manufactured and exported in finished instruments and none of the allied governments had been

willing, after the outbreak of the war, to allow such an indispensable material to be exported in quantity.

From the point of view of proper fire control instruments therefore the moment chosen for the entry of the United States into the conflict was perhaps the worst that could have been selected.

The Committee of the Naval Board, which had been commissioned to investigate the optical glass resources of the country, discovered and reported substantially this situation. In his report the chairman (Mr. Baekeland) outlined the conditions which he had found and recommended to the consideration of the Navy Department that the whole matter be placed in the hands of the Bureau of Standards, which, in his opinion, was in the best position to take up the question intelligently and to propose an effective solution.

The next active step to provide a supply of optical glass was taken by the National Research Council in April, 1917, a few days after our declaration of war. The speaker was delegated by this body to make a personal canvass of the possible resources of the country, visiting all who were known to have knowledge of the manufacture of optical glass, and to report with recommendations.

This inquiry developed the fact, contrary to the news items on the subject which had begun to appear rather frequently in the papers, that optical glass in small quantities had been made in this country long before the year 1917. It is to the credit of the elder Macbeth, of the Macbeth-Evans Company, that the first attempt to manufacture in this country glass of high optical quality was undertaken in the early nineties and a number of creditable lenses, some of considerable size, stand as monuments to the success of this effort. Nevertheless the undertaking was financially unprofitable and the enterprise was abandoned after a short time. In 1912 the Bausch & Lomb Company, who were the largest manufacturers of instruments of precision in the United States, determined to control their own glass supply, and with the aid of a Belgian expert began making optical glass in their plant at Rochester. A factory fire soon afterward consumed the building and some delay occurred, but in 1914 very creditable samples of optical glass were produced in this plant. Because of the demands of the great war this industry flourished and the initial small pot furnace was soon replaced by other larger ones, and at the period

when this record begins (March, 1917) this company was engaged upon large contracts for field glasses for the Canadian Government and for the British Field Service, in which the glass used was in part, at least, of American manufacture. The total output of this plant which might be considered available for American use at this critical moment was perhaps as much as 2000 pounds per month, a quantity sufficient in their expert hands for a considerable number of optical instruments.

It is also a matter of record in the annual report of the Director of the Bureau of Standards, dated June 30, 1915, that the possibility of our being drawn into the European conflict had been foreseen and the consequent possibility of our being suddenly called upon to provide an independent supply of glass of optical quality had been considered there. Some time during this year a small furnace was erected at the Bureau Laboratory in Pittsburgh, in which a number of pioneer essays in this field were attempted. Chief among these was the effort to provide a suitable container or melting pot in which the glass could be melted without contamination. The clay which had been used in glass melting for most commercial purposes in this country before the war was also of foreign origin, and when this supply was cut off American pot makers found themselves without competent knowledge of American clays which might be substituted for the imported clay. The records of the United States Geological Survey show that clays are found in this country in greater quantity and variety than in any of the European countries, but in the absence of adequate knowledge of how to use them, the chance of developing suitable melting pots from American clays was not encouraging. The Bureau of Standards made a serious effort in the years 1915 and 1916 to meet this situation, but it happens that a glass-melting pot of suitable size for this purpose requires for making and burning a period of about four months, so that the development of the necessary experience proceeded slowly.

At the time when our situation was most critical (March, 1917) the experimental work of the Bureau of Standards had not proceeded far enough to be of great assistance. Their experimental work with pots was not finished and only one type of optical glass (a borosilicate crown) had been successfully made.

During this period also, and more or less in collaboration with the Bureau of Standards, Mr. Carl Keuffel, of the firm of Keuffel

& Esser, had erected at the works of his company in Hoboken a small furnace in which also a successful attempt had been made to produce this type of glass, using pots of his own design and manufacture.

In the year 1916 the Spencer Lens Company, of Buffalo, erected a small plant at Hamburg, N. Y., and also began the manufacture of optical glass with a view to replace the foreign sources of supply already closed by the war. The capacity of the plant, as operated during the late months of 1916 and early 1917, was not above 200 pounds per month, and actual production was considerably less than this, being uncertain both in quantity and quality.

The chemist of the Hazel-Atlas Company, Washington, Pa., Mr. Duval, who was also reputed to have been a successful maker of optical glass in Europe in earlier years, had already set up an extemporized furnace in this country and had melted a single pot of glass of such quality as to win favorable consideration from a firm as exacting in its requirements as the John A. Brashear Company, of Pittsburgh.

It also appeared that in 1915 the Pittsburgh Plate Glass Company, at its plant in Charleroi, Pa., had begun making considerable quantities of spectacle glass and other high grade special glasses not particularly intended for optical instruments, but nevertheless of excellent commercial quality. Incidentally, this plant proved to be the largest in the United States which might be deemed immediately available for the production of optical glass, and if it should be possible to improve the quality up to the standards of the army and navy, might contribute much to relieve the immediate need.

This then was the situation at the period of our entry into the war. One firm was regularly producing glass of fair optical quality at the rate of perhaps 2000 pounds per month. There was another plant of much larger capacity which might be deemed available, but which had never produced glass of strictly optical quality, and four others, including the Bureau of Standards Laboratory, all of which were very small and still in the experimental stage.

The estimated requirements of the army and navy, as forecast by the General Munitions Board in the month of April, 1917, amounted roughly to 2000 pounds per day.

There were very earnest conferences in the National Research Council following upon this discovery before a course of action was determined upon. Finally it was decided to ask the President of the Carnegie Institution of Washington to allow the resources of the Geophysical Laboratory, both in men and apparatus, to be applied to this overwhelming task. The obvious reason for this was, not that optical glass had ever been made there, but that at the Geophysical Laboratory there was available a larger and more experienced group of silicate chemists than perhaps could be found elsewhere. This permission was granted by authority of the Executive Committee of the Institution upon the 18th of April, 1917, twelve days after the declaration of war. From that time until the conclusion of the armistice on November 11, 1918, practically all of the resources of the Laboratory were placed at the disposal of the Government without expense to it either direct or indirect.

Upon the assumption by the Laboratory of this responsibility several steps were taken immediately :

(1) To initiate a canvass through the United States Geological Survey to discover a source of supply of sand of the highest possible quality.

(2) By a canvass of chemical manufacturing establishments to discover a source of potash with which to supply this indispensable ingredient which hitherto had been regularly imported from abroad.

(3) To delegate a group of men to make analyses of typical glasses of foreign manufacture with a view to determining the ingredients used and the relation between chemical composition and optical properties.

(4) To delegate a group of men to aid the Bausch & Lomb Company in the development of new varieties of glasses which might be needed and in securing greater perfection of quality in those already made.

(5) To canvass the manufacturers of melting pots throughout the country and to make a careful examination of the iron content of these pots with a view to guarding against contamination of the glass melt by iron, for it is a well known fact that of all the substances regularly present in optical glasses, iron is the one which most diminishes transparency and is also the one most difficult to eliminate.

The results of this canvass will be adverted to in a moment.   .

After the organization of the General Munitions Board, of which Mr. F. A. Scott, of Cleveland, was the first chairman, the question of an optical glass supply was felt to be very acute. A number of sessions were held and eventually a committee was appointed (May, 1917) to give continuous attention to the task. The committee consisted of Prof. Millikan, of the University of Chicago, chairman; Mr. Stratton, of the Bureau of Standards, and the present speaker.

After the canvass of the situation, which has been outlined above, it appeared clear that all of the sources of optical glass available in May, 1917, could together produce only about half of the quantity required, assuming that all of the glass produced was of quality suitable for war equipment. At that time the Bausch & Lomb Company alone were producing glass of such quality. Moreover, it was estimated that they might, by extending their plant, carry approximately one-half of the war load. To maintain the other half there appeared to be but a single course open, namely, in some manner to make the Charleroi plant of the Pittsburgh Plate Glass Company available and to place someone in charge of it who should have sufficient knowledge of the requirements and technique to raise the quality of glass produced there to the standard which the Government required and which they had not hitherto attained alone.

After several conferences a plan was agreed upon whereby the Pittsburgh Company should undertake to perfect their glass under the direction of the Bureau of Standards Laboratory, located nearby. It appeared to the committee that such an arrangement might work out advantageously, for the chemists of the Geophysical Laboratory were already in charge at Rochester and a gentle rivalry between the two institutions might prove an incentive to each, of a kind which might bring results more rapidly than without such an arrangement. In addition to this the Bureau of Standards had received through the Naval Board the sum of $75,000 for the extension of its own plant in Pittsburgh, and it was thought that with this organization thus strengthened and given control of the facilities at Charleroi, the other half of the war production would be attained.

In practice there was some disappointment in carrying out this plan. At the close of the year 1917 the Bausch & Lomb Company

was producing in Rochester at the rate of about 40,000 pounds per month, while the Pittsburgh Plate Glass Company had not been able in the eight months interval to provide any glass which would pass the Government inspection standards.

At that time Mr. Raymond, General Manager of the Pittsburgh Company, decided that the basis upon which they were producing was not destined to prove successful, and application was made to the Geophysical Laboratory to divide its force at Rochester and to permit a number of the chemists who had been successful there to take up the Pittsburgh problem. This was practically laying the entire load upon the Geophysical Laboratory, because only one month previous (December 4, 1917) the Laboratory had taken the responsibility for production in the third of the optical plants, that of the Spencer Lens Company, of Buffalo, and every man of its force was occupied to the limit of his capacity. Indeed the requirements at that time were so pressing that there was need to strain the situation to the breaking point if necessary in order to secure the maximum producing capacity out of every available furnace. Dr. J. C. Hostetter, of the Geophysical Laboratory staff at Rochester, with three associates, Drs. Adams, Williamson, and Mr. Roberts, from the Washington Laboratory, and Dr. Taylor, of the Bureau of Standards Laboratory, by invitation, undertook this most difficult problem, beginning on January 1, 1918. Dr. Bowen was soon after detached from the Spencer Lens Company plant and added to this group.

Speaking at this distance of the situation which then confronted us, it is perhaps not unfair to say that we would have done more wisely to have further enlarged the plant at Buffalo or at Rochester, or both, to the size required to produce the glass needed rather than to attempt the immense problem which the Charleroi plant presented. Sixteen furnaces were available which had already been used for glass-making, and others which might be turned to the task should circumstances require, but all of the furnaces were of an old type without regeneration and without means for controlling the temperature in individual furnaces within 100 degrees centigrade, whereas it was already established by our experience at Rochester that a control as close as 5 degrees must be continuously maintained in each individual furnace to insure success.

The Pittsburgh Company was liberal in its plans and the Gov-

ernment placed a large contract, amounting to 100,000 pounds, with the company in order to afford an incentive to press forward as rapidly as possible the improvements which were needed. Certain specified improvements were even authorized to be charged against cost of the glass delivered. Nevertheless production lagged, and it was not until the following July that the output contemplated in the original plan was attained. In the intervening months the average production had been from 3000 to 6000 pounds per month, which afforded a modest contribution in addition to the production elsewhere, but it amounted to scarcely 10 per cent. of the production of the Rochester plant throughout the spring months.

In contrast to this situation, and to the difficulties encountered at Charleroi, it is interesting to consider the progress of the small plant of the Spencer Lens Company, at Buffalo, in the same interval. This plant was new and though small was capable of competent control. Accordingly production up to the existing capacity began in the month of December and continued uninterruptedly thereafter until June, 1918, when it was approximately doubled by additional building, and in August when it was doubled again. Two of the members of the staff of the Geophysical Laboratory (Drs. Fenner and Bowen) went from the Rochester plant to start this furnace, and of the first 22 pots which were put through after their arrival not one failed.

In the Spring of 1918 the General Munitions Board was replaced by the War Industries Board, a considerably larger and more diversified body, but, like its predecessor, advisory rather than authoritative in character. Nevertheless by agreement of the Purchasing Departments of the various Ordnance Bureaus authority was placed in its hands to exercise a certain amount of supervision of contracts with a view to increasing the effectiveness of production by regulating the size of contract and time of delivery to the producing capacity of the manufacturer, and by aiding him in various ways. In particular, with respect to optical glass, the reorganization terminated the existence of the Optical Glass Committee of the General Munitions Board, and in its place provided a certain amount of direct authority over manufacturing processes. For example, in the contract for 100,000 pounds of optical glass issued to the Pittsburgh Plate Glass Company early in 1918, the specifications of the glasses and the con-

ditions of inspection were written into the contract, together with
the requirement that all of the glass to be delivered under the
contract should be produced under the direct supervision of the
Director of the Geophysical Laboratory, who was designated "In
Charge of Optical Glass Production, War Industries Board."
This arrangement had the effect of giving to the representatives
of the Laboratory in the various plants over which they exercised
control, absolute authority to prescribe the raw materials which
should be used and the details of all the processes through which
these materials were to be passed up to the time of the inspection
of the finished product, which was done by authorized represent-
atives of the Ordnance Department of the branch of the service
to which the glass was consigned.   The Geophysical Laboratory
at no time exercised any authoritative control over the inspection
standards or the manner of applying them.

This organization and procedure was common to all of the
three large plants until the conclusion of the armistice in Novem-
ber, 1918, and except for a small quantity of glass manufactured
in the Laboratory of the Bureau of Standards at Pittsburgh,
and a still smaller quantity made by the Keuffel & Esser Company,
covered all of the glass produced for war uses during this year.

Leaving now the Washington organization and its relation
to the manufacturing plants, some account may properly be given
of the steps taken, (1) to raise the quality of the glass to meet
the inspection standards set by the Government, (2) to increase
production to the magnitude required by the war needs.

Although the phrase " optical glass " has become familiar
through notices printed in the papers from time to time during
the progress of the war, in point of fact but little has been printed
of the qualities which serve to distinguish optical glass from other
glasses.   In general it may be said that optical glass is the highest
type of clear glass known in the art.   A single illustration may
serve to explain my meaning.   Ordinary spectacle glass in its
conventional use appears clear and white, but if it is held so as to
permit looking through the glass edgewise considerable color may
usually be detected, so that it might occur to one as doubtful
whether it would be possible to see clearly through the same glass
if the thickness were represented by the width of the glasses
rather than by their shortest dimension.   For optical purposes,
notably in the case of prisms used in range finders and periscopes,

very much greater thicknesses than this are common, and a glass for such a purpose must be optically perfect throughout its thickness, which may often reach four or five inches.

The qualities assigned for test in establishing standards of inspection for optical glass, very briefly, are these:

(1) Homogeneity, by which is meant uniformity in chemical composition, freedom from striation, bubbles, inclusions and crystallization.

(2) A constant refractive index and a constant dispersion ratio throughout.

(3) Freedom from color.

(4) High transparency.

(5) Both physical and chemical stability, by which is meant durability under exposure to the weather, chemical fumes, etc., as well as toughness and hardness for protection against misuse.

(6) Physical homogeneity, by which is meant freedom from strains or internal stresses caused by uneven cooling of the molten glass.

To produce glasses with these qualities the first obvious requirement is high chemical purity in all the ingredients of the glass itself and the second either an insoluble pot in which to melt it, or one in which the ingredients entering the glass from the pot shall not impair the development of the above qualities.

The search for such materials, which was immediately instituted by the Geophysical Laboratory when it was first authorized to take up the optical glass problem, yielded the following results:

After a search of the sand quarries from the State of Washington to Florida, including more than forty-five different localities, a sand was finally located at Rockwood, Mich., of which the analysis indicated greater purity than that from any known source of supply, even including in the comparison the wonderful sand of Fontainebleau (France) which has been used both in France and England for artistic glassware for a hundred years.

A number of sources of potash were canvassed, in the course of which much disappointment was experienced. Not only were the efforts, which were first put forth in this country to make potassium carbonate, less successful than might be wished, but the cost of manufacture was almost prohibitive. European potash was laid down in New York before the war at six cents per pound, while the major portion of the American-made potassium car-

bonate used in the manufacture of optical glass, cost the Government in the neighborhood of $1.00 per pound. This fact is of some importance as an indication of the outlook in store for an independent optical glass industry in this country now that the war has closed.

It is to the credit of the Armour Company, of Chicago, that the first potassium carbonate of adequate purity was produced in this country. Subsequently it was found possible to substitute the nitrate for the carbonate, either in part or altogether, and so to obtain a salt which was equally good and much more generally available. But even so, the necessary provision for potash in some of the glasses remained to haunt us throughout our entire experience of glass manufacture without reaching an altogether satisfactory final solution. Sulphur and chlorine, one or both, were very often found, and a small percentage of either is usually sufficient to give a milky cast to the finished product.

In view of the long period of time needed (about four months) to manufacture, to dry, and to burn the pots which must contain the glass during melting, to which allusion has been made above, this investigation also was never quite satisfactorily concluded. In the beginning it was of course necessary to purchase in the open market such pots as were then available. These had not been made with a view to their use in the manufacture of glass of high purity, and in general were found to contain about one hundred times as much iron per cubic centimeter as could safely be permitted in the finished glass (2.0 per cent., compared with 0.02 per cent.). It is therefore a matter of easy calculation to show that, however pure may be the sand, potash, lead, and other ingredients required for a particular glass, there was more than an even chance that enough of the contact surface of the pot would be dissolved in the mixture to contaminate the contents of the glass beyond the limits of tolerance. Between the iron, which diminishes transparency, and the sulphur, which even in very small quantities causes milkiness, many a pot of promising glass found its way into the Genessee River during the early days at Rochester without in any way aiding our troops at the front.

Nevertheless our pot makers, with a single exception, put forth a splendid effort to meet the situation by conducting experiments simultaneously in several plants, and it proved possible within four or five months to obtain containers in which the raw ma-

terial was sufficiently free from contaminating elements so that glasses of a purity comparable with the best European glasses could be obtained. This conclusion was aided considerably by the discovery that if the pot was first burned in a furnace at a temperature considerably higher than any which would be required for melting the glass, burned even until the side walls showed signs of sagging and the surface became more or less glazed, then the solution of pot material in the glass was very greatly diminished. By the use of this process, even more perhaps than through more intelligent selection of clays, it became possible to melt nearly all of the glasses with a minimum of contamination from the pots.

Of course in the manufacture of optical glass, as opposed to other branches of the glass industry, a pot is used but once, which makes it very much easier to provide means for avoiding or limiting the solution of pot material in the glass. An absolutely insoluble pot is unknown for the reason that all of the oxides which enter into glass composition, as well as the refractory oxides used about the furnace, are mutually soluble.

Toward the close of the war period the porcelain type of pot developed by Dr. Bleininger, of the Bureau of Standards, was very successfully used with the glasses made in the Bureau Laboratory, but was not successfully manufactured by other pot makers in time to be of service. This pot possessed a smaller iron content and in general a lower solubility than any pot prepared for optical glass during the war period, but unfortunately could not be made generally available.

From the Laboratory point of view the most interesting problem was presented in the initial studies at the Bausch & Lomb plant, (1) of processes through which to obtain constant composition, and (2) to establish a definite relation between chemical composition and the optical constants prescribed by the requirements of the service.

In this connection it should be borne in mind that a glass solution is never in equilibrium, but is constantly changing in composition. Lead oxide and the alkalies are somewhat volatile, while the containing vessel continually contributes alumina, silica, and usually iron. It is therefore necessary for the student of glass melting who wishes above everything to attain to a prescribed chemical composition, to establish precise data upon the

rate of evaporation at particular temperatures of those ingredients which pass out of the furnace and, at least approximately, the rate of solution of the pot in the glass. Knowing these quantities and the time of exposure necessary to mature a glass which is free from stones (that is, completely dissolved) and free from tiny bubbles, of which there is constant danger with every shift in the temperature, it is possible to produce successful pots of glass of accurately uniform composition and so to define and to reproduce definite optical constants.

The general relation between composition and optical constants is obviously the main issue in optical glass manufacture, and is therefore very conspicuous by its almost complete absence from the literature of the subject. Much of the optical glass technique has been enveloped in profound secrecy in all the three countries where it has been mainly produced, and although more or less freedom has been permitted in the publication of technical details of temperature, of stirring, and even of chemical composition, the manner of varying optical constants in any desired way through changes in composition has remained a trade secret up to the present time.

In this connection it is perhaps interesting to remark parenthetically that at the time when the French Liaison Commission visited this country after our entry into the war, to aid us with their experience in the production of war material, it was not permitted to divulge any details regarding the manufacture of optical glass upon the ground that the integrity of the existing glass monopoly in France had always been respected by the Government and must be so still, in spite of the war pressure. England adopted a similar attitude, and so in this one branch of the service the United States was left to proceed unaided to endeavor as best it might to reproduce within the period of a few months all of the experience which had been attained in optical glass manufacture since the days of Abbe and Schott in the early eighties.

It became necessary therefore to proceed much as a scientific man is accustomed to proceed in other unknown fields, by varying quantitatively each ingredient present and plotting the results in curves through which the effect of each ingredient on the optical constants of the resulting glass might be determined. This was done systematically and very successfully, so that within a period of three months from the beginning of our efforts it became pos-

sible for Dr. Fred E. Wright, who was in charge of the work at Rochester, to write formulæ for any of the typical glasses required for war service without advice from the glass expert employed there, and indeed to prepare new glasses directly from the optical specifications when needed. A special heavy flint, for example, which was desired by the Government, was made with no more than two trials. To properly appreciate just what this progress means, it may perhaps be recalled that in the days of rule-of-thumb glass making, as many as 150 essays were necessary before a glass of predetermined optical constants resulted. This kind of knowledge applied intelligently commanded for the Laboratory workers the immediate respect and confidence of the workmen who had hitherto believed these things to be shrouded in impenetrable mystery, and contributed in no small degree to the rapid progress and whole-hearted coöperation obtained.

Again later in the war, when the development of airplanes made it necessary to prepare a new type of airplane camera for battlefield photography, a special barium glass was made upon comparatively short notice which fulfilled the optical requirements with little if any variation.

Perhaps a brief digression may be permitted here to indicate the suddenness with which perplexing problems were precipitated by special inquiries like this. Most of the optical glasses in general use fall into two types, generally designated as flint and crown, both of which when melted form viscous mixtures which give little difficulty except in maintaining homogeneity. The barium crowns and flints, on the other hand, appear almost as thin as water in comparison and possess the disadvantage that they are taken up by the pots almost as rapidly as coffee is taken up by a lump of sugar. The most serious question encountered in connection with the barium glasses therefore was not to discover the composition appropriate to the prescribed optical constants, but to provide a suitable container in which the ingredients could be melted.

There is one other problem to which allusion should be made which is on the whole the most persistent and difficult problem encountered in the entire glass technique; it is the question of obtaining a homogeneous product. By this the glass-maker understands primarily freedom from striations or cords. It is fairly obvious that in a mixture, parts of which are volatile and into which other ingredients are entering through the solution of the

containing vessel, inhomogeneity is constantly to be feared. More-over, in the heavier glasses the differences of specific gravity among the ingredients amount to as much as three or four to one. These are the causes of the glass-maker's cords and striations, of which traces are found in the finest product of the glass-maker's art. It is to meet this situation that stirring is resorted to at several stages of the process.

Theoretically, if the stirring were vigorous enough, homogeneity would result except for the losses due to evaporation and the accessions (chiefly of alumina) from the pot wall; practically, this result is not so simply attained. Practically, indeed, perfect homogeneity in glass melts is unobtainable. Alumina in particular, even when present in very small quantity, yields a glass of lower refractive index than the surrounding mass and becomes immediately conspicuous. Incomplete solution of silica grains will sometimes leave a train through the mixture resembling a comet's tail. Such striations are very persistent and require stirring, either constantly or at frequent intervals, not only during melting but during the cooling, in order to diminish, so far as possible, the convection currents or other migration within the melt. Even with all the precautions taken which the experience at the several factories suggested to us, rejections by Government officials were mainly on account of striations.

Toward the close of the war a new scheme of melting was developed, partly in the hope of providing a quicker process than the normal one and partly in order to render the striations innocuous by orienting them perpendicular to the plane of light transmission. This consisted in melting and stirring in very nearly the usual way, but instead of setting out the pot to be slowly cooled through a period of several days in order to be able to break it up without undue losses, the hot glass was taken from the furnace and poured upon a steel table in front of an advancing roller which rolled it out in a sheet, similar to the procedure in the manufacture of ordinary plate glass. Cooling the glass in the pots made it possible to reject the outer portions of the glass mass wherein usually the striations were found concentrated. Pouring left all of the striations in the finished product, and perhaps aggravated them somewhat, because the pouring had to be done at a temperature where the glass was by no means free from them. The results obtained by the rolling process, however, were fairly

satisfactory, excepting for the most exacting requirements, because the striations were rolled out in planes parallel to the surface of the plate, so that it was possible to cut lenses from such a sheet in which the striations should all be perpendicular to the line of sight. Such glass was in general not well adapted for prisms or other optical forms through which light must pass by more than one path, but for lenses, even of considerable size, it proved satisfactory.

It should be borne in mind perhaps that when glass must be produced in vast quantities for a war emergency the utmost requirements of precision may not be exacted; indeed, deliberate relaxation may become necessary. As soon as the standards arbitrarily fixed by the War and Navy Departments had been attained further efforts to improve the quality of the glass gave place to efforts to increase the quantity practically without limit. It is therefore not quite fair to say that the war glass produced in this country was equal to or superior to that obtainable from abroad before the war. Strictly speaking, this result was not attained, nor indeed attempted, although the technique was so far perfected that it was within the power of those who participated to produce glasses of quality equal to those made abroad when necessary. In fact, through the application of phosgene to remove the traces of iron from the sand and from the pots, it is altogether probable that greater transparency could be obtained than is usual in European glasses. It is in this quality of transparency alone that American glasses have usually fallen somewhat behind their European prototypes. A process for the employment of phosgene for this purpose was successfully developed by Lieutenant S. F. Cox in the Bausch & Lomb plant during the Summer of 1918, but did not come into general use because the time required for such purification could be better spent, in the prevailing emergency, upon increased production rather than upon a superfluous refinement.

It also proved practical to carry out the entire melting process within a period of 24 hours. Where before the war two weeks was not an uncommon period through which to nurse the melting operation in order to secure the best results, a 24-hour schedule was worked out by Doctor Morey at the Spencer Lens Company's plant under which glass equal in quality to any which was supplied to the Government during the war period was produced.

In so brief an outline as this must be, it is perhaps unnecessary to consider other details of the process of optical glass-making such as the relation between rate of cooling and the break-up of the mass with a minimum of waste, the process of moulding the raw blocks to suitable shape for inspection and suitable size for the subsequent operations of the lens maker, the grinding of opposite surfaces for inspection purposes and the details of the inspection process, and finally the painstaking annealing through the perfection of which alone accurate grinding becomes possible or worth while and a permanent configuration is assured. All these processes required time and conscientious attention to detail for their working out, and in general require modification for each type of glass made, but they set no problem for the chemist and physicist beyond the requirement of endless patience and attention to detail.

Of the results of these efforts it need only be said that within a period of four months after the entry of the United States into the war the production of optical glass within this country had been doubled, the methods had been rendered more effective, the number of types had been increased and, moreover, a degree of confidence had been established indispensable for the state of the times and of the task. I quote from a memorandum of Doctor Wright, written on July 28th, after three months of experience in the manufacture of optical glass at Rochester: " In the course of our work we have realized that the making of glass of high quality is not beset with mysteries to be solved only by the intuitive genius of one specially trained in the art, but that it is a straightforward scientific problem, requiring for its solution the application of methods of attack and control common to all scientific problems of high precision."

I venture to remark that before the beginning of this experience at the Bausch & Lomb plant no member of the group of men who undertook the war work there had ever followed a pot of glass through the process of melting. Moreover, with the long record of secrecy continuously maintained in two of the glass producing countries, and in the third also, except for a portion of its early history, no information was available from without. Here as in many other cases, however, when the details are finally brought to light by time, the maintenance of secrecy has frequently been shown to be a cloak to cover limitations rather than

profound knowledge. The processes of glass-making are simple and the traditions of the glass-house are as often the result of cumulative superstition as experience. The heart of the whole matter lies in the relations between the ingredients at the various temperatures through which they pass and their reaction velocities. The solution of these relations is not a task for the glass-house, but rather for the most exacting application of silicate chemistry at high temperatures.

The Geophysical Laboratory has published freely the results of its experience in the glass industry, and in so far as this experience was not available before, it is so now for any individual or group who may wish to make a beginning of a permanent optical glass industry in this country.

The portion of my subject which deals with the future of the industry must, however, remain vague. Three firms entered this field, to produce optical glass on a large scale for war purposes, of whom two were able to make use of the product in instruments of their own manufacture. This portion of the industry may endure in whole or in part. The third successful producer of optical glass has to find his market outside his own plant, and this market is rather too intangible to be attractive as a business venture.

It remains true to-day, as it did during the war period, that the cost of several of the necessary ingredients is necessarily greater in this country than in European countries where similar products originate. In quality our raw materials are equally good, our experience in technique is adequate if not equally extensive with some of our European contemporaries, but the cost of potash, for example, will always lay a burden upon the American product, and other ingredients might be mentioned which fall in the same category. If there were a market sufficient to stimulate production on a very large scale these difficulties could be overcome by improved technique and organization, as in the case of other conspicuous American industries, but the demand for optical glass will probably never be large, and the incentive to large-scale processes and cheaper production will therefore probably always be lacking unless the Government determines upon a definite program of preparedness. The instrument maker may find it advantageous to make his own glass for the reason that he can then arrange for the precise optical constants which he wishes to use in his instrument, and he may have them within a period of a few

days instead of weeks or months, but the trade itself will perhaps
never furnish sufficient incentive to build up a large industry in
this country.

Moreover, if it may be said without appearing to reflect upon
similar industries abroad, it is, I think, no secret that successful
makers of optical glass in other countries have had to look for
their profit in other lines rather than in their optical products.

In closing this account of the effort which was made to supply
the Government with its indispensable requirements of optical
glass, it gives me unusual pleasure to pay a personal tribute to the
whole-souled patriotism and untiring patience of all members of
the staff of the Geophysical Laboratory and of the participating
manufacturing firms, without whose efforts this record would
have been impossible. It is to them an everlasting credit that
through their exertions the great, and, in many respects, un-
paralleled, task of developing an entirely new industry was
accomplished, literally out of nothing in the way of special
experience because of the atmosphere of secrecy with which this
particular industry has been so persistently enshrouded. It was
also accomplished in time for the requirements of the service.

The total quantity supplied by these firms from April 6, 1917,
to November 11, 1918, the war period, is approximately 650,000
pounds,* divided as follows:

Bausch & Lomb Optical Company .... 450,000 pounds, approximately
Spencer Lens Company .... 75,000 pounds, approximately
Pittsburgh Plate Glass Company .... 125,000 pounds, approximately

In addition to this production the Bureau of Standards sup-
plied a little more than 19,000 pounds, or about 2.8 per cent. of
the total war-time production.

Except for occasional shipments of a few pounds from the
Parra Mantois Company, in France; from the British Govern-
ment plant at Derby, and that produced by the Keuffel & Esser
Company, of New York, for their own contracts (about 9,000
pounds for the period of the war), no other optical glass was
available to the Government for war operations.

* Informal records of the Geophysical Laboratory; the official record
of the War Industries Board has not yet been released for publication.

THE INDUCTION ELECTRICAL FURNACE.*

BY

G. H. CLAMER.

Member of the Institute.

I will confine my lecture to the Induction Type of Electric Furnace, and trace the development of the induction furnace art. I will more particularly confine it to its application in the brass industry, especially the wrought brass industry. What is included in the designation " brass " is all copper and zinc alloys, containing from five to forty per cent. of zinc, and varying smaller percentages of tin, lead, etc. All alloys within this range of composition are not commercially so designated, but I wish it understood that in referring to brass in this lecture, I include all alloys within this range. Such alloys constitute a very great proportion of the total tonnage of copper alloys produced.

In this art, prior to the advent of the electric furnace, the rolling mills of the country adhered almost universally to the ancient practice of melting in small crucibles, having a maximum holding capacity of 300 pounds. These small crucibles are placed in a so-called " pit furnace," usually using anthracite coal for fuel.

A recent writer has stated: " Of all the present-day industrial arts that have come down to us from the ancients, there is none that has changed less in the technic of its practice than brass melting. The melting and casting of the metal in a brass mill is the most important step in the whole process of making brass material, because any failure here cannot be rectified by later manipulation. However, in spite of the vital character in this stage, it is the one in which the least advancement has been made."

An interesting illustration of a brass foundry (Fig. 1) appearing in Ecker's " Untererdische Hofhaltung," published in 1682, bears a truly remarkable resemblance to the equipment of the casting shop of our largest and most modern brass mills. The only radical difference between the furnace as shown, and the typical modern pit furnace, lies in the method of carrying away the products of combustion.

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* Presented at a joint meeting of the Institute and the Philadelphia Section, American Institute of Electrical Engineers, held Wednesday, March 17, 1920.

In the modern furnace the products of combustion are carried off on the side and into the stack, thus increasing the rate of combustion and also adding to the comfort of the workman, whereas in the ancient furnace the products of combustion were allowed to escape into the open shop. The method of handling the crucible and pouring the brass into the molds, and the type

FIG. 1.
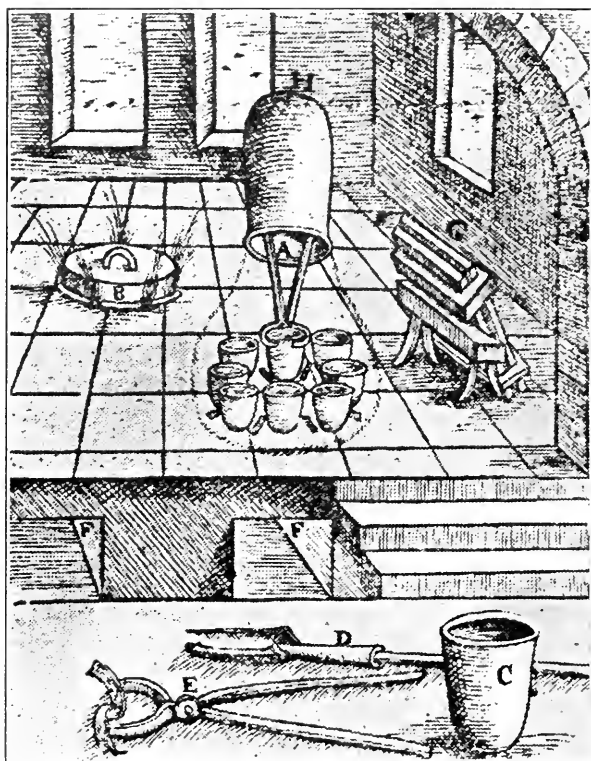
Ancient brass mill.   Illustration in Ecker's "Untererdische Hofhaltung," published in 1682.

of molds used, were not radically different from the method and equipment in use to-day.

A very interesting curve prepared by H. W. Gillette of the Bureau of Mines is shown in Fig. 2. The lower curve shows melting points of the various copper-zinc alloys. The upper curve is a plotting of the temperatures at which zinc is volatilized from the various alloys, and the intermediate curve shows the necessary

FIG. 2.
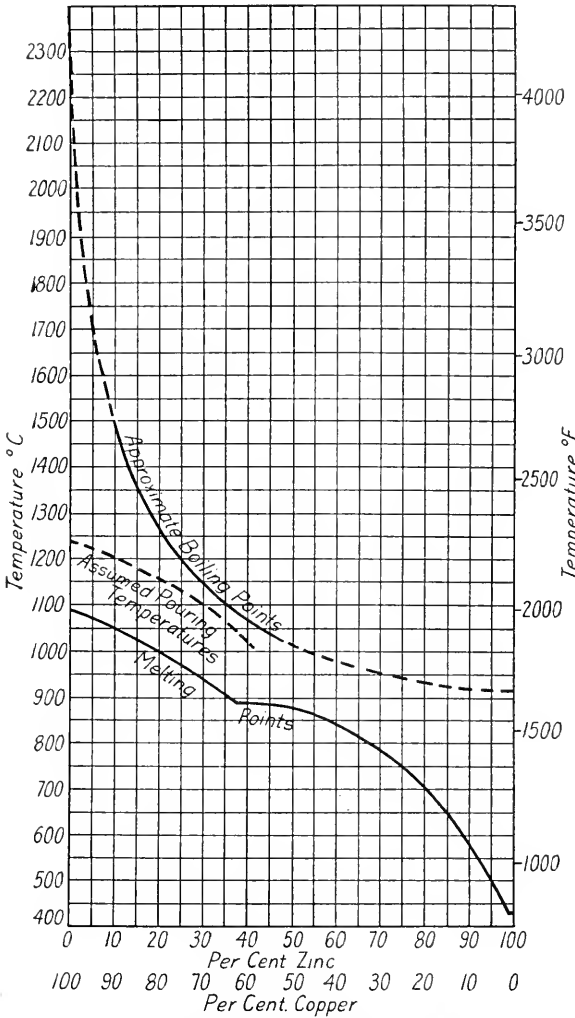
Curve prepared by H. W. Gillett of the U. S. Bureau of Mines, showing graphically the small difference in temperature between the average pouring temperature and the temperature at which zinc volatilizes from copper-zinc alloys. This curve illustrates forcibly the value of temperature control, such as is possible only in the induction furnace, the induction furnace being the only form of furnace in which accretion in temperature of bath ceases immediately as the circuit is interrupted.

pouring temperature. These curves are of particular interest in showing in graphic form the small margin in temperature between the pouring temperature and the point at which zinc volatilizes

from those alloys that are of greatest commercial importance, namely, those containing between 30 and 40 per cent. of zinc.

It is these underlying facts in connection with such alloys that make us turn our attention with so much assurance of success to the electric furnace. It is only in an electric furnace which provides an absolute temperature control that it becomes possible to pour with certainty at the correct temperature, and at the same time reduce the loss of zinc by volatilization. In the induction furnace, of proper design, in which heating results in the metal bath itself, ideal control is assured.

The brass mills have experimented from time to time with oil and gas furnaces, both of the open-flame type, and tilting crucible furnaces, holding large crucibles. Experience has proved that

Fig. 3.
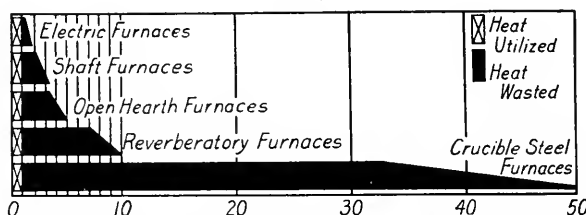
Diagram prepared by Alfred Stansfield, Birk's Professor of Metallurgy in McGill University, Montreal, showing losses of heat in melting metals in various forms of fuel furnaces, and in electric furnaces.

the average quality of the brass melted in such furnaces will not satisfactorily meet commercial demands. Such brass lacks uniformity, and is oxidized, and often sulphurized due to its contact with excess of air and fuel gases. The metal losses in such furnaces, due to oxidation and volatilization, are excessive.

It is for the above reasons that the old type crucible furnace, with its homœopathic charges, has been adhered to until the advent of the electric furnace.

Fig. 3 indicates losses of heat in melting metals, in the various forms of furnaces. The light spaces showing the proportion of the heat utilized, and the dark spaces the proportion of heat wasted.

Electric furnaces have been variously classified, but a general classification can be made under two heads:

1. Those in which the heat is transferred to the metal from an outside source.

2. Those in which the electrical energy is converted directly into thermal energy in the metal to be heated, due to its resistance to current flow.

It is the latter type of furnace that is most extensively used in the wrought-brass industry, and it is this type of furnace to which I will confine my talk to-night.

Such a furnace is in reality a current transformer, and is known as an induction furnace.

When an electric current flows through a conductor, magnetic lines of force are formed around the conductor in concentric rings. If the current is discontinued, this field dies down similar to a rubber.band that is stretched into a large circle and then released. These lines of force, in dying down, cut the conductor. Whenever lines of force cut a conductor, a voltage is induced, and if the electric circuit is placed so that the lines of force from the first conductor will cut it, then a voltage will be induced in it. With an alternating current, the value of the current, and, hence the number of lines of force, is continually changing from zero to a maximum and then back to zero. The rate of this change is called the frequency. In order to increase the number of lines of force and have them take a certain path in order that as many as possible of the lines will cut all of the conductors, iron is used to interlink the conductors. Air is a poor magnetic conductor; iron is many times better. The induced voltage is proportional to the number of cuts in unit time. For example, if we have 1000 lines of force cutting 10 conductors in one second, a certain voltage will be induced. Now, if we double the lines of force or double the number of conductors or cut the time in half, the voltage will be double. We may now express these three conditions in a formula:

$$V = C \times F \times T \times L$$

$V =$ the voltage, $C =$ a constant, $F =$ the frequency, $T =$ the turns, $L =$ lines of force.

The combination of two coils and an iron core interlinking them constitute what is called a transformer. By means of a transformer any voltage desired may be obtained, either higher or lower than the supply voltage. Formula (1) applies to both coils of a transformer, the primary coil being the one connected to the supply; the secondary coil the one with the changed voltage.

As the constant C, the frequency F, and the number of lines L are the same for both coils, then it follows that the voltage is proportional to the number of turns. This may be expressed in a different way, as follows: "The voltage per turn is a constant."

For example, if the primary voltage of a transformer is 220 and the primary coil has 22 turns, the voltage per turn is 10. Now, if the secondary coil has 5 turns, its voltage will be 5×10, or 50. If the turns of the secondary be changed to 10 turns, its voltage will be 100. The efficiency of a transformer will average about 97 per cent., therefore, for simplicity, we may say that the input equals the output. Let P_1 equal the primary power, P_2 equal the secondary force, E_1 equal the primary volts, E_2 the secondary volts, C_1 the primary current, C_2 the secondary current, T_1 the primary turns, T_2 the secondary turns. Then

$$P_1 = E_1 \times C_1 \qquad P_2 = E_2 \times C_2$$
$$P_1 = P_2 \qquad E_1 \times C_1 = E_2 \times C_2$$
$$\frac{C_1}{C_2} = \frac{E_2}{E_1} = \frac{T_2}{T_1}$$

The current is inversely proportional to the voltage and inversely proportional to the number of turns.

The foregoing rules are of great importance in the design of transformers and also of induction furnaces, for an induction furnace is simply a short-circuited transformer under control. It is an ordinary transformer in which the secondary is formed by molten metal.

There are two injurious factors to guard against in the design of horizontal open-ring induction furnaces—namely, "pinch effect" and low-power factor.

"*Pinch Effect.*"—When high currents are sent through molten conductors, the cross-section of the conductor tends to contract. This contraction will, if the current be sufficiently increased, finally interrupt the circuit at the point of smallest cross-section. This does not occur when steel is being melted in the induction furnace, if the furnace be not forced. Because of the high resistance of steel, the current required to melt is not sufficient to cause the "pinch effect." But, in the case of low resistance metals, as copper and brass, "pinch effect" interferes with the proper running of the furnace. This condition occurs only in induction furnaces which have the molten secondary in a horizontal plane, and of the open channel type.

Low Power Factor.—It is essential in the proper design of a transformer to have the primary and secondary coils as closely together as possible. If this is not done, many of the lines of force will not interlink the two coils, and, hence, a low power factor will result. In the induction furnace, the molten secondary cannot be placed so closely to the primary coil as desired on account of the necessary refractory material needed for heat insulation, and furthermore, the secondary must have a certain length to give the required resistance.

The first induction furnaces developed were of that form known as the open channel type. In furnaces of this type, the power factor is always low and becomes lower with increased size of furnace and increased frequency of current used. In furnaces of this construction there is a varying resistance of the secondary loop, depending upon the amount of metal in the channels. When the furnace is first started, the metal in the channels is low and the resistance is, therefore, high, and as further amounts of metal are added, and the amount of metal in the channel becomes greater and the cross-section thereby increased, the resistance is diminished. It is not possible in open channel induction furnaces to increase the current density beyond a certain maximum because of the restriction or actual break of the current path, due to the so-called " pinch effect " previously referred to. The fact that it is necessary to limit the current density in open channel furnaces because of the pinch effect was first observed by Dr. Carl Hering and the theory and formula whereby the magnitude of this force can be calculated was worked out by Dr. Edwin F. Northrup.

The first induction furnace was invented by Edwin Colby (Fig. 4), of Newark, N. J. This was a simple ring type of furnace in which the secondary consisted of a single turn of molten metal interlinking a magnetic circuit. In the Colby type of furnace, the primary coil was placed outside of the secondary circuit. Colby was in the platinum business and his desire was to produce a furnace in which platinum could be melted in a non-carbonaceous atmosphere. Platinum, when melted in contact with carbon, absorbs that element to some degree and makes it difficult to work. Colby did not succeed commercially in accomplishing that which he set out to do, but he did give to the world a type of electric furnace which for many other purposes

has been developed into one of great usefulness and importance. From a theoretical standpoint, this type of furnace is of the highest efficiency, and is one in which the charge of liquid metal is under perfect temperature control. In the induction furnace the

FIG. 4.
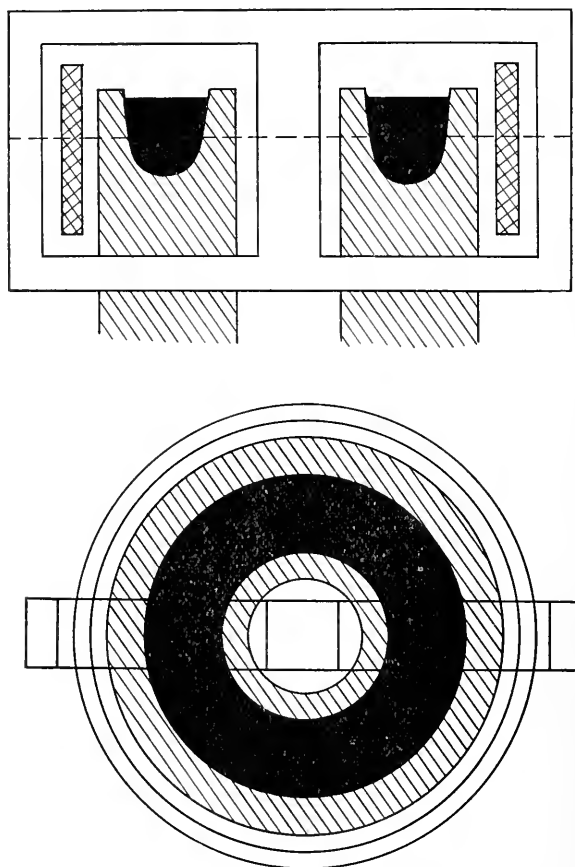
Original open channel induction furnace as invented by E. A. Colby, 1888. In this furnace is embodied the basic idea upon which was founded the Induction Furnace Art.

heat is generated within the metal itself and the current flow is absolutely steady, because of the constant resistance.

Deferranti, in England, patented a similar induction furnace at approximately the same time as Colby. He also placed the primary coil outside of the secondary, the magnetic leakage was therefore very great and the power factor quite low. Both Colby

and Deferranti, no doubt, were afraid to place the primary within
the secondary circuit because they had not worked out a proper
means for protecting the primary coil from the effects of heat
generated in the molten secondary.

FIG. 5.
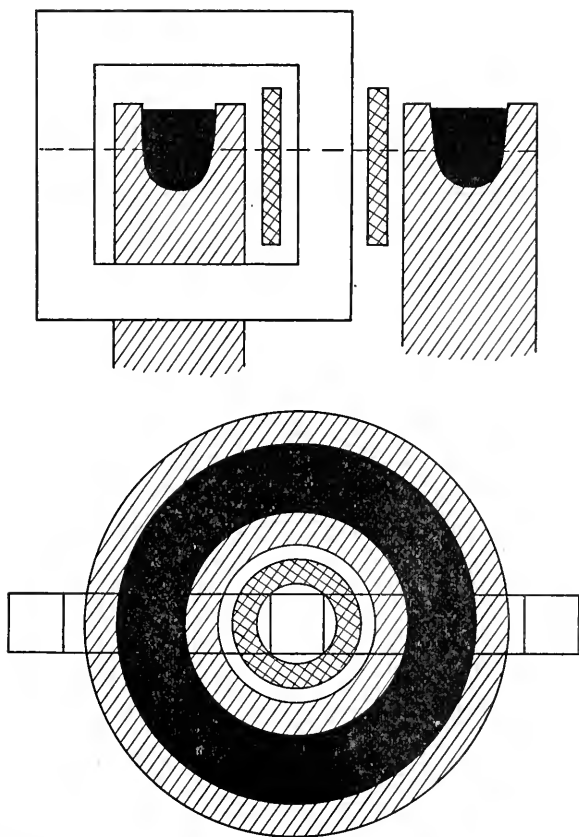
Invention of Kjellin which made possible, by reason of the improvement in power factor as
compared with the Colby furnace, commercial application of the induction furnace.

Kjellin a few years later patented a furnace (Fig. 5) in which
the primary coil was placed within the secondary.   Magnetic
leakage was thereby greatly reduced and the power factor, on
furnaces in which the secondary ring was of relatively small
diameter, could be maintained quite high.   With increasing diame-
ter of the secondary ring, the power factor becomes correspond-

ingly lower. It was this invention of Kjellin that put the induc-
tion furnace in position to become a commercial competitor of the
arc type of furnace for steel melting.

Because of the effect of the size of the secondary ring on the
power factor, the Kjellin type of furnace could be applied com-
mercially only in relatively small sizes, if currents having normal
frequency are used. Fairly large furnaces have been made by
using current of low frequency, and in one form of furnace of
this type, frequency so low as five cycles has been used.

Fig. 6.
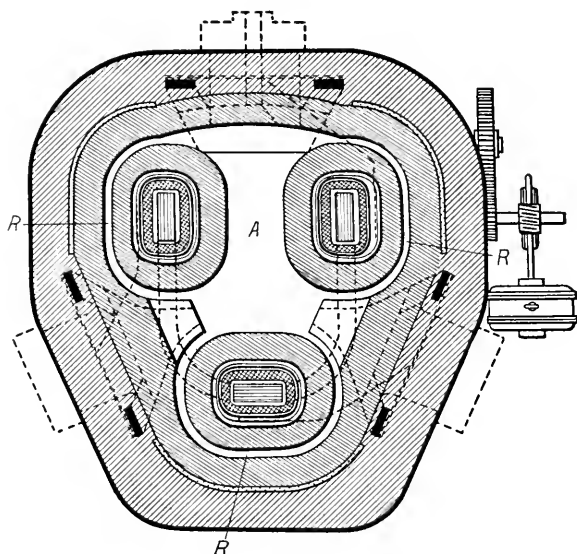
Röchling-Rhodenhauser furnace. A commercial form of steel furnace developed and used ex-
tensively in Germany in sizes up to eight tons holding capacity.

Many improvements have been made upon the Kjellin furnace
in details of construction. Important improvements were made
by Colby covering design of transformers, having as their object
the cooling of the primary coil and greater ease of dismantling.

One of the greatest improvements is embodied in the now
well-known Röchling-Rodenhauser furnace. A two-phase fur-
nace of this type (Fig. 6) is nothing more than two Kjellin fur-
naces placed together and in which the working hearth forms a
section of the secondary circuit of each of the phases. It is
possible, by restricting the cross-section in the channel portion

of the secondary loop, to maintain a fairly high resistance and cut down the magnetic leakage. By reason of the common hearth resulting by this construction, fair-sized working space is provided. Magnetic leakage is further cut down by placing an auxiliary coil in such position that current of relatively high voltage is inducted therein. This current is led to pole pieces placed at the opposite sides of the hearth and is conducted by means of a conductor of the second class through the bath. The resistance set up in this conductor of the second class provides additional heat units to the bath. In a furnace of three-phase construction, the same general construction is used, and in this case a still larger hearth area is possible.

Another of the important inventions is that of Otto Frick, of Germany, which is an attempt to provide a furnace having low self-inductance, and therefore relatively high-power factor. The means provided for accomplishing this result is to place the primary winding above the annular hearth, constituting the secondary, both the primary and the secondary, of course, being interlinked by the magnetic circuit. Certain mechanical features are provided, affording greater convenience in operating. This is a type of furnace which has been introduced to some extent in Germany, and a few years ago a large furnace, I believe of thirty tons capacity, was installed in Lebanon, Pa. This installation, due more particularly to refractory troubles, has been far from succesful.

Recently the General Electric Company have solved the refractory difficulty, at least for furnaces of small size. In the General Electric furnace, the overhead primary coil placement is also used. One furnace of this type is reported in successful operation at the Pittsfield plant of the General Electric Company.

Primary coils have been placed in practically every conceivable position in relation to the secondary. In the patent of C. Grunwald, a construction is provided whereby the " motor effect " due to the repelling force of the current in the primary winding upon the secondary is counteracted, the result of this repelling force is to bank the liquid metal at the outer circumference, which causes an inclination of the exposed surface of the bath. Such inclination of the bath exposes the high surface to oxidation, and pockets slag in the depressed area, thus causing rapid deterioration of the lining surrounding the smaller diameter of the channel.

A number of patents have been issued to Hiorth, but apparently none of these have come into commercial use. In one of his inventions he shows a placement of primary coils permitting of greater accessibility to the bath. Two primary coils are used. One above the bath, and one below. The upper coil having a smaller diameter than the secondary channel, and the lower coil having a greater diameter than the secondary channel. In another of his inventions, he attempts to overcome one of the most serious objections to the induction furnace as a means for refining steel. It is claimed that in the ordinary induction furnace, slag action does not proceed rapidly because the slag is relatively cooler than the metal. The reverse condition exists in the arc type furnace. In the arc furnace, the slag is necessarily hotter than the metal, and it is claimed that due to this fact the refining action proceeds at a very rapid rate.

Hiorth accomplished the heating of the slag by providing a dam, or obstruction, in the path of the secondary channel, whereby the flow of current is diverted to the slag above the obstruction. As the slag is of relatively high resistance, there is a rapid conversion of electrical energy into thermal energy at that point. The temperature of the slag is thereby raised, and more energetic slag action supposedly results.

Grönwall Lindblad and Stälhane have invented a furnace of the ordinary ring type providing an elongated portion of the ring in the form of a loop, the channels of which are brought into close proximity, thereby cutting down self-induction. With such construction of the secondary a bath of higher resistance is provided, having greater holding capacity without diminishing the power factor.

A furnace similar in principle to that of Grönwald Lindblad and Stälhane was invented by Gin. In this furnace a number of loops are used giving a circuit of relatively high resistance which therefore permits of the use of higher voltage, and gives a high-power factor. This furnace was not successful because of refractory difficulties. Highly heated metal on two sides of a refractory wall, without cooling provision, is not practicable.

A further invention of Gin provides a means for circulating the liquid metal of the bath. Instead of the usual ring, a series of inclined connecting channels are provided. The bottoms of the receptacles of the bath are longitudinally sloping, and the top

portion of each receptacle is connected by a channel to the shallow portion of the next. The " Joule effect " which varies in an inverse ratio with the section of the molten mass is less intense in the top portion of the open channels. As the two liquid masses, which connect through closed conduits, have different densities on account of the difference in temperatures, an upward movement of the liquid molecules in the closed channels is produced. Continuous circulation thereby results.

Solomon is credited with an invention which provides for the usual annular secondary, constructed in the form of a removable crucible. The secondary having its magnetic circuit broken by a section of butt joint construction permits of the convenient withdrawal of the crucible. Mechanical means are provided for ejecting the crucible.

Geherkens uses a construction which restricts it to melting low-fusing point metals. The secondary in this furnace forms the outside casing or furnace chamber. The walls of same are of relatively great cross-section, so that heating effects are at a minimum. Two sections of the secondary circuit are so designed that they are of relatively small cross-section. In these sections of restricted cross-section, heating effects are produced, and the heat so generated is transferred to the metal bath, and an insulating lining keeps the bath from coming into electrical contact with these resistors.

Charles P. Steinmetz invented a furnace which can be described as a cascade induction furnace in that there is a double transformation. Both transformations are provided under conditions of minimum magnetic leakage. In the first transformation the secondary takes the form of a water-cooled casting, and the bath to be heated is contained therein, in the form of a ring-shaped channel, electrically insulated from the casting. A magnetic circuit interlinks both the casting and the bath, so that a second transformation results. There is no record, so far as I know, of this furnace ever having been used.

A patent to James R. Wyatt (Fig. 7) discloses an open ring furnace of the Röchling Rhodenhauser type, in which is provided more rapid circulation due to " motor effect." " Motor effect," as I will later on describe, occurs at the acute angles " 36 " because the current path at such points takes opposite directions. Owing to the more rapid circulation thus produced, as compared with

the circulation in the Röchling-Rhodenhauser furnace, considerable advantage results, namely, more rapid refining and diminished destructive effects upon the lining, due to the more rapid ejection of the overheated metal from the channels.

A furnace designed by Benjamin has for its object a means for counteracting the banking of the bath due to motor effect. I have before described how Hiorth accomplished this by electrical means. Benjamin seeks to accomplish the same effect by mechanical means.

A furnace invented by Bally operates on an entirely different principle than the many other furnaces before exhibited, in that

FIG. 7.
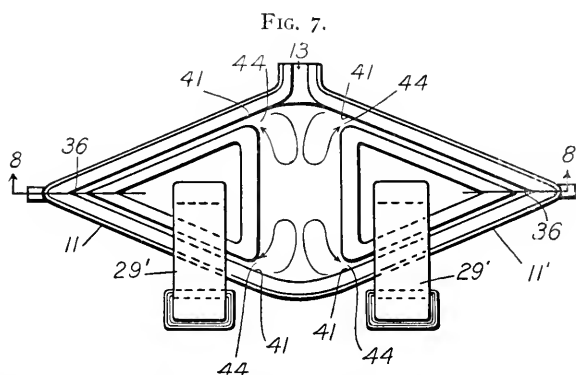
Ajax-Wyatt furnace of open channel type in which an in and out circulation in each leg of the secondary loop is provided. This circulation results by reason of the fact that the current in turning an acute angle travels in opposite directions in the conductor on the two sides thereof.

inductive effects result in this furnace by reason of a rotary field and a stationary armature. If in an induction motor the armature is so wedged that it can not rotate, it burns out, because of the rapid conversion of electrical energy into heat instead of motion. In this furnace the bath to be heated is the armature. The inductor with an exciting current rotates within the annular bath or armature and heating thereby results.

All the furnaces thus far described are of the open-channel type.

Charles P. Schneider, President of the Creusot Steel Works of France, and immediate past President of the British Iron and Steel Institute, was the original inventor of the closed channel induction furnace in which there was a pool of metal that exerted a hydraulic pressure upon the molten metal in closed

channels or channels constituting the secondary loop. In the furnace as described and constructed by Schneider, a constant resistance of the secondary is maintained. In this type of furnace the power factor can be made relatively high because it is possible to have comparatively close looping of the secondary and because of its high resistance. It is claimed by Schneider that circulation is maintained by thermal effect. Pinch force was present in the Schneider furnace, but not recognized—at any rate, the hydraulic head resulting from the head of metal over the liquid metal in the channels was sufficient to prevent rupture of the circuit if pinch force of such magnitude were present which in an open channel furnace would break the circuit.

The Schneider furnace is shown diagrammatically in Fig. 8. This plate shows circular melting pot in communication with two

Fig. 8.
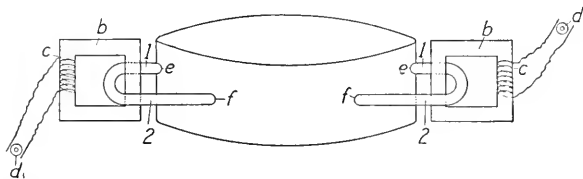
Original closed channel induction furnace invented by C. P. Schneider, President of the Creusot Steel Works, France, and past President of the British Iron & Steel Institute.

" U "-form heating tubes 1 and 2, slightly inclined in such a manner that their communications e and f with melting pot are at different levels. Through each loop, formed by tubes 1–2, passes a magnetic frame or iron core (B) carrying primary winding (C) traversed by alternating current coming from dynamo (D), whereby magnetic lines of force are produced in the iron core (B).

Schneider was the first to heat a pool by circulation of metal from an outside resistor channel and to cause *also circulation of the pool thereby*. This, in his patents, he claims broadly as follows: " In combination a chamber for holding molten metal, one or more pipes communicating with said chamber so constructed as to permit circulation of molten metal, an iron core encircling said pipe or pipes and means for producing lines of force in said core."

The Schneider furnace was not successful because the circulation was sluggish and overheating resulted in the resistor channels.

Other closed channel furnaces have been invented by Deferranti and Wallin.

The Deferranti furnace differentiates from the Schneider in that it shows the transformer in a horizontal position, and the furnace is arranged to tap from the bottom.

In the Wallin furnace the secondary loop is also placed in a vertical position, but in this case part of the secondary is made up of slag or ore mixture having relatively high resistance. It was Wallin's idea to combine a vertical ring induction with a shaft furnace.

As I have stated before, about 1909 Dr. Carl Hering observed the "pinch effect" in a molten circuit carrying current of high density.

Fig. 9.
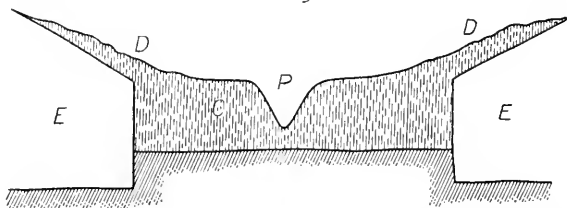
Drawing showing effect produced by passing of current of high density through a molten conductor in a straight open channel. The body of liquid metal contracts in the centre and flows up over the electrodes. As the physical appearance is that of pinching the molten conductor, the phenomenon has been termed "pinch effect" by Dr. Carl Hering, who first observed it.

Doctor Hering passed a very heavy current through the molten metal contained in a trough between two electrodes "E" (Fig. 9). When the current reached a certain density, a severe depression occurred at point "P" and the liquid metal flowed back over the electrodes at "D." He at first thought that a leak in the bottom of this trough had allowed the metal to run out. An examination showed that this was not the case, but that it was due to electrical action.

His observations were recited to Dr. Edwin F. Northrup, who, as I stated before, explained the phenomenon and worked out the mathematics in connection therewith. Then with an understanding of the magnitude of this force, Doctor Hering applied it to useful advantage in the construction of an electric furnace.

He passed the current through a channel submerged below molten metal (Fig. 10). The current then, if of sufficiently great density, causes the metal to circulate as shown.

In the furnace as originally constructed by him, current was

led by electrodes to columns of liquid metal retained within a tubular wall. These columns of metal were of relatively small cross-section and carried currents of high density. The circuit was com-

FIG. 10.
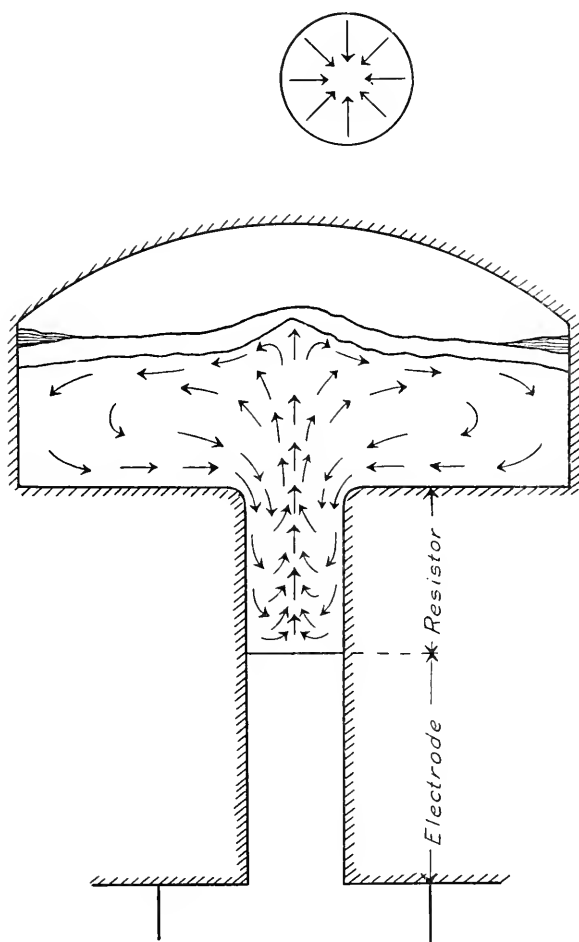
Diagram illustrating the action of "pinch force" as applied in the Hering Electrode Type Furnace.

pleted by the metal bath. Heat was developed in the metal in these tubes, known as resistors, and energetic circulation ensued by reason of the " pinch force."

Certain inherent difficulties became apparent in the Hering

electrode type of furnace as the development work progressed. Briefly, these are as follows:

1. Melting of electrodes back to the point where further melting was only prevented by the water cooling. Many means for preventing this were tried but without success.

2. Because of the shortness of the solid portion of the electrode, hence the proximity of molten metal to the water, an element of danger was encountered and high heat losses resulted.

3. Because of the necessity of imbedding electrodes in the refractory material, cracking of the refractory resulted, due to differences in the coefficient of expansion of the electrode as compared with the refractory material. Liquid metal flowed in these cracks and resulted in short-circuiting.

As the induction furnace uses no electrodes, these difficulties are entirely overcome.

A number of trials were made some years ago of melting non-ferrous metals in the *open channel type* of induction furnace, but invariably these met with failure and the promotors of this type of furnace have freely acknowledged that such furnaces are not successful for melting the non-ferrous metals or alloys. The difficulty lies in the high currents occasioned by the necessity of having the channels sufficiently wide for practical purposes and because the material is of high conductivity. With such high current density as must necessarily be used, the " pinch force " manifests itself to the extent that rupture of the circuit takes place. The power factor is very low and the resistance so variable that the furnace is entirely impracticable.

It is a fact that the *closed channel furnace* in which a hydraulic head is maintained by means of molten metal in a pool above the channels, such as originally described by Schneider, and so constructed that circulation of *sufficient magnitude* is *produced* to *eliminate* the heated metal from the channels before volatilization takes place, is the *only form* of induction furnace, using normal frequency current (I will refer to high frequency induction heating later), that has promise of commercial success for melting non-ferrous metals.

I was associated with Doctor Hering in the development of the electrode " pinch effect " furnace, as was also Mr. James Wyatt. As before stated, one of the main difficulties to be overcome in this form of furnace is to prevent melting of the electrodes. It

was thought that such melting was largely the result of " pinch pressure " which exerts its force in both directions from the centre of the resistor. Hot metal is forced inward against the electrode as well as upward into the bath. As a means for preventing a backward circulation within the electrode, the electrode was made of right-angle form. In this construction the current path turned two right angles, one in the electrode, and the other in its passage from the electrode to the resistor.

Wyatt observed that some peculiar action was going on in a steel furnace with electrodes so constructed. The question arose,

FIG. 11.
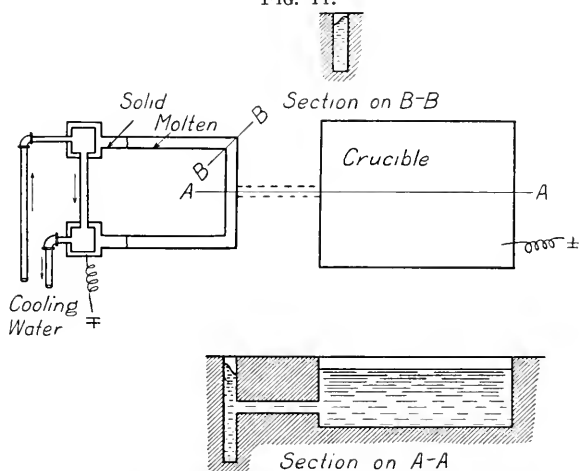
Duplication of the electrode form having 90 degree angle similar to that used in the three phase steel furnace, connected with the Hering resistor, and crucible. Decided action of metal on the line *BB* piling up against outside walls was observed. We questioned if this action was due to backward flow of metal resulting from "pinch force" in resistor, or if it was due to "motor effect."

Was this due to " skin effect " or " motor effect "? He determined to carry on a series of experiments to determine the underlying cause.

I will now describe briefly those experiments. The metal used in the following described experiments was pure lead, and the forms were moulded in ordinary moulding sand.

(Fig. 11.) Duplication of the electrode form having 90-degree angle similar to that used in the three-phase steel furnace, connected with the Hering resistor, and crucible. Decided action of metal on the line " *BB* " piling up against outside walls was observed. We questioned if this action was due to backward

flow of metal resulting from " pinch force " in resistor, or if it
was due to " motor effect."

(Fig. 12.) Duplicating the conditions in the electrode of
previous plate maintaining the same cross-sectional area and same

Fig. 12.
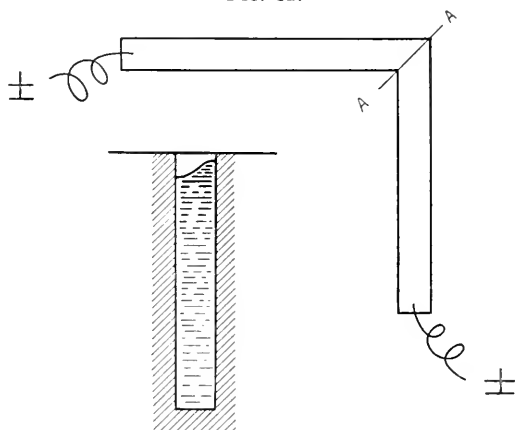
Section on A-A

Duplicating the conditions in the electrode of previous plate maintaining the same cross
sectional area and same current density. No resistor. As the current was not sufficient to melt
the metal, it was melted with a torch, and when the current was sent through it, the same bank-
ing effect at the corner *AA* resulted.

current density. No resistor. As the current was not sufficient
to melt the metal, it was melted with a torch, and when the current
was sent through it, the same banking effect at the corner
" *AA* " resulted.

(Fig. 13.) Again duplicating the same conditions existing

Fig. 13.
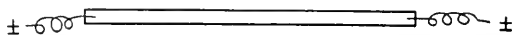
Again duplicating the same conditions existing in the electrode, Fig. 11, but without Hering
resistor, and without angle of Fig. 12. Here again the metal was melted with a torch, and when
the current was turned on there was no action, the current being insufficient to cause a notice-
able "pinch effect," this experiment being on cross sectional area of electrode proportions.
No action visible.

in the electrode, Fig. 11, but without Hering resistor, and without
angle of Fig. 12. Here again the metal was melted with a torch,
and when the current was turned on there was no action, the
current being insufficient to cause a noticeable " pinch effect,"
this experiment being on cross-sectional area of electrode propor-
tions. No action visible.

(Fig. 14.)   The first attempt to embody the " motor effect " idea as a means for circulating liquid metal.   In this case two legs of the triangle formed the resistor, and the other leg the bath. There was a decided banking effect in the angle farthest from the bath, and banking effect of less magnitude at both angles, that the resistor formed with the bath.   In the construction shown, there is a transformer, the magnetic loop of which surrounds one

FIG. 14.
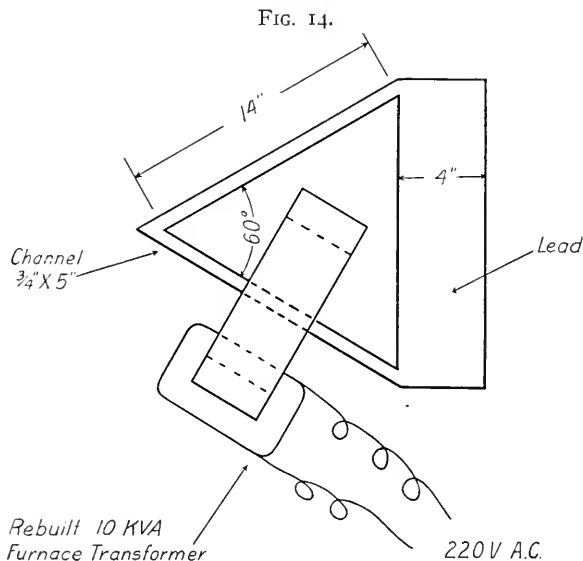
The first attempt to embody the "motor effect" idea as a means for circulating liquid metal.   In this case two legs of the triangle formed the resistor, and the other leg the bath. There was a decided banking effect in the angle farthest from the bath, and banking effect of less magnitude at both angles, which the resistor formed with the bath.   In the construction shown there is a transformer, the magnetic loop of which surrounds one leg of the resistor, and the primary coil is placed on one of the legs outside of the same.

leg of the resistor, and the primary coil is placed on one of the legs outside of the same.

(Fig. 15.)   Experiment to note the difference in action between the resistor having an acute angle and one of circular form. In this experiment the transformer was again looped about the resistor in the same manner as in Fig. 14, and it was noted there was a decided banking and overheating effect at point " B," and banking and choking effect at points "A" and " C."   This can be accounted for by the " motor effect " set up at points "A" and " C," and the absence of " motor effect " at point " B."

(Fig. 16.)   This shows the next attempt made to better the

power factor by placing the primary coil completely within the secondary, and to get better mechanical construction. The bath of metal in this experiment was of open-top construction. Decided motor effect was noted at the angle, and some choking at points " B " and " C."

In this experiment it will be noted that the angles " B " and " C " are 99 degrees, whereas in the previous experiment the angle
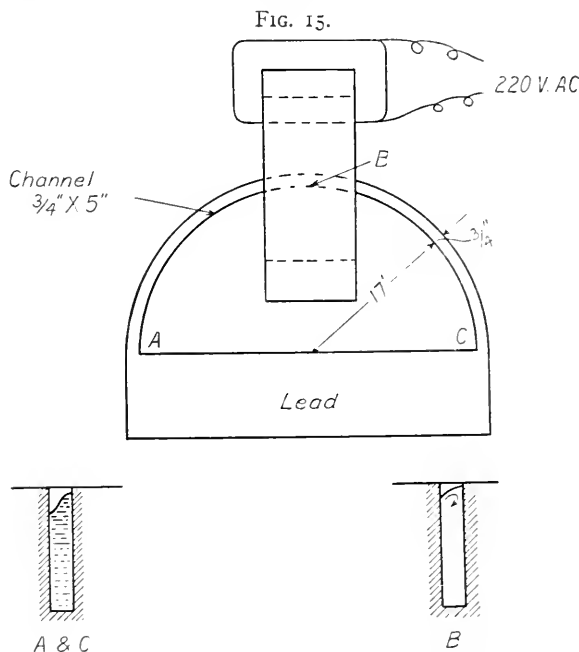
FIG. 15.

Experiment to note the difference in action between the resistor having an acute angle, and one of circular form. In this experiment the transformer was again looped about the resistor in the same manner as in Fig. 14, and it was noted there was a decided banking and overheating effect at point B, and banking and choking effect at points A and C, and the absence of "motor effect" at point B.

with the bath was 60 degrees. Less motor effect was noted in this experiment, and is explained by reason of the greater angle.

In Fig. 17 the design is such that the maximum motor effect is exerted at the angle on the cross-section line "AA" and the angle was eliminated at points " B " and " C." By reason of the elimination of this angle, motor effect is diminished, or absent, and the electro-magnetic force producing motor effect in the angle at " A," has full force in clearing the channels, there being no choking at points " B " and " C."

(Fig. 18.)   Same construction as Fig. 17, with the exception
that the resistor is here submerged.   In the latest design of fur-
nace the same conditions prevail, except that the resistor is in a
vertical position.

FIG. 16.
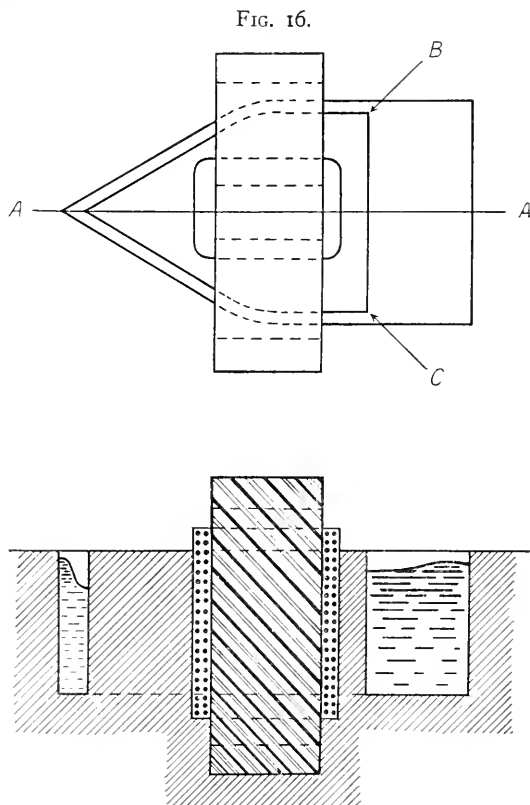
Section on A-A

This shows the next attempt made to better the power factor by placing the primary coil
completely within the secondary, and to get better mechanical construction.   The bath of metal
in this experiment was of open top construction.   Decided "motor effect" was noted at the angle,
and some choking at points *B* and *C*.
      In this experiment it will be noted that the angle at *B* and *C* is one of 90 degrees, whereas
in the previous experiment the angle with the bath was 60 degrees.   Less "motor effect" was
noted in this experiment, and is explained by reason of the greater angle.

(Fig. 19.)   Shows in view one and two the vertical ring form
of Ajax-Wyatt electric furnace, having in general a body or bath
and a channel portion forming an acute angle connected thereto.
The channel portion is interlinked with the transformer having
the primary coil wound upon the central leg of the magnetic

frame, and in a position practically concentric with the resistor. Means are provided for pouring.

This furnace is similar to the Schneider furnace in that it uses a closed channel with pool above the channel, and circulation

Fig. 17.
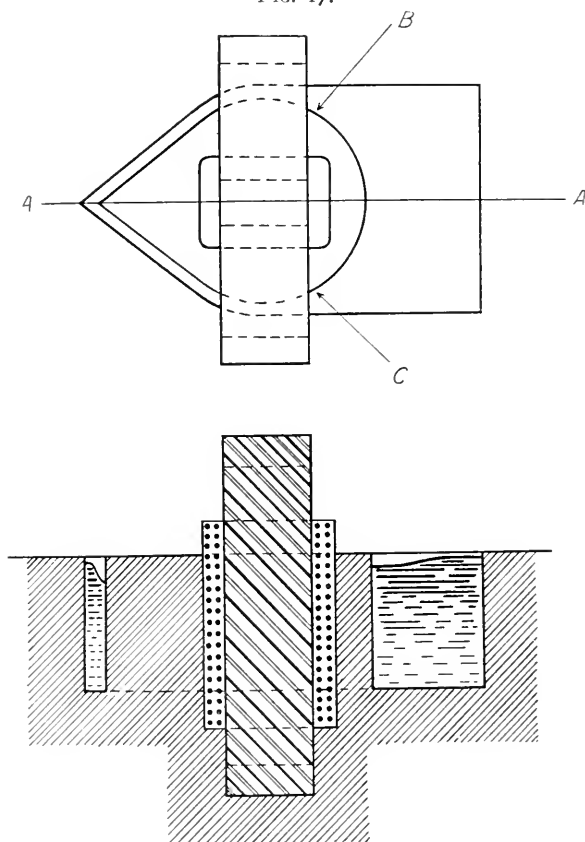
Section on A—A

This design is such that the maximum "motor effect" is exerted at the angle on the cross section line *AA* and the angle was eliminated at points *B* and *C*. By reason of the elimination of this angle, motor effect is diminished, or absent, and the electro-magnetic force producing motor effect in the angle *A*, has full force in clearing the channels, there being no choking at points *B* and *C*.

of the liquid metal in the channel. Without circulation, a furnace of this type would be entirely impracticable for the reason that it is in the channel that the heat is generated, owing to its restricted cross-section, and relatively higher resistance.

Circulation can result from " Joule " effect alone, but such circulation is very sluggish and is not sufficient for melting alloys high in volatile constituents.   To melt such alloys the circulation must have sufficient rapidity to prevent volatilization and breaking of the circuit by reason of the expanded gases.

FIG. 18.
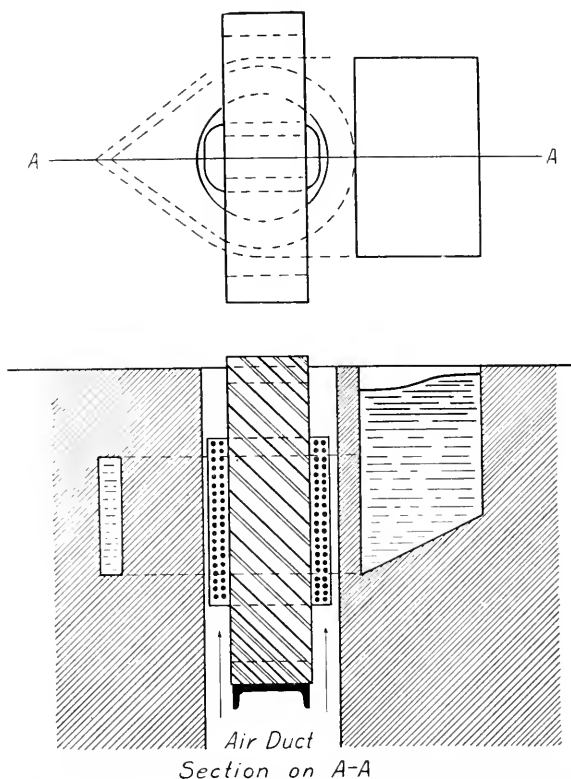
Air Duct

Section on A-A

Same construction as Fig. 17, with the exception that the resistor is here submerged.   In the latest design of furnace the same conditions prevail, except that the resistor is in a vertical position.

If a furnace is so designed that pinch pressure of sufficient magnitude exists, there will be a much more rapid circulation, and the circulation, due to motor effect, is still more active than that produced either by Joule or by pinch effect alone.

In the Ajax-Wyatt furnace some pinch force is exerted under existing conditions, and Joule effect also acts in an advantageous manner, but the predominating force is that resulting from motor

effect. Motor effect of considerable magnitude is set up at the
acute angle which is in the current path of the secondary loop
at a point farthest from the pool.

Dr. Edwin F Northrup has calculated the forces due to
" motor effect " as they exist in the Ajax-Wyatt furnace and has
charted these forces. Their relative magnitude is strikingly
shown. The mathematical calculations of " motor effect " forces,

FIG. 19.
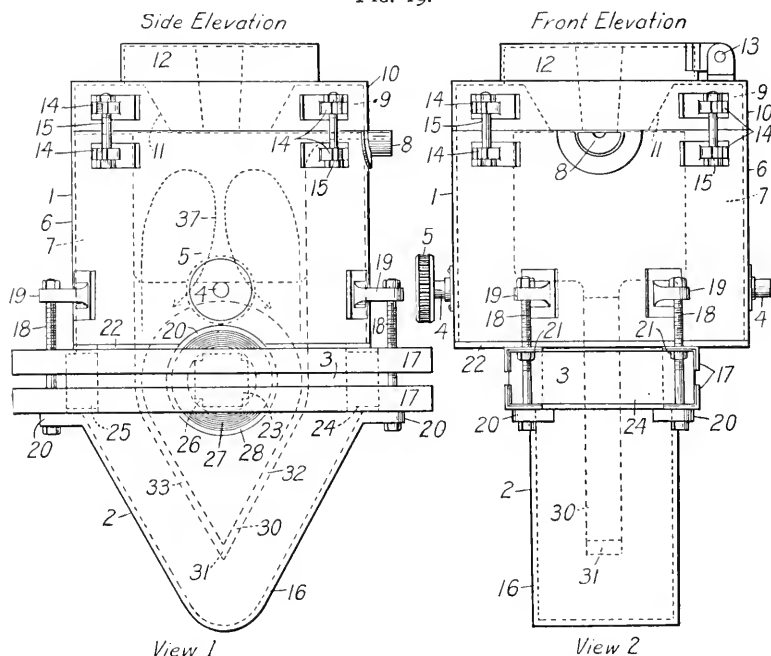
Shows in views one and two the vertical ring form of Ajax-Wyatt electric furnace, having
in general a body or bath and a channel portion forming an acute angle connected thereto.
The channel portion is interlinked with the transformer having the primary coil wound upon
the central leg of the magnetic frame, and in a position practically concentric with the resistor.
Means are provided for pouring.

and " pinch pressure " independently and collectively as they exist
in this furnace, form a highly creditable accomplishment.

In the Ajax-Wyatt furnace it is possible to melt 60/40 brass
without volatilization of zinc in the channels of the secondary
circuit, so long as the cold metal is being fed into the furnace,
or the bath, in its entirety, has not reached the temperature at
which the zinc is volatilized. It is interesting to know that just
as soon as the bath reaches the correct pouring temperature, the

needles on the instruments begin kicking. The test now used by the melter in the brass rolling mills to determine the casting temperature is to immerse an iron bar in the molten metal. If the melter feels a kick upon the bar, he pronounces the temperature satisfactory. This kick that is felt is simply due to the so-called boiling of the metal, *i.e.*, volatilization of zinc.

The furnace may be fed with turnings, cabbaged material, ingots, etc. The charge may be added rapidly as there is no danger of solidifying the metal in the secondary channels or in the lower portion of the pool above them, the only precaution necessary being to exercise care to prevent bridging of the charge. The furnace is entirely noiseless in its operation, very cool on the outside of the jacket, uses no water in cooling, therefore, absolutely safe from any danger of having the heated metal come in contact with water and its consequent results. The shape of the hearth closely approximates that of an ordinary crucible, in fact very closely approaches the ideal for minimum of heat losses, which is a spherical form.

It is possible to tightly seal the furnace to prevent oxidation. The heat is generated in the charge itself, and at the bottom of the charge. All the forces effective in the channels have the tendency to carry the heated metal upwards, *viz.*, motor effect, pinch effect, and Joule effect, and so bring it in contact with the metal to be melted, consequently there is constant and energetic automatic circulation. The conditions in all these respects are ideal for high efficiency and minimum of metal losses.

The power factor of a 30-kw. furnace is 85 per cent. and of a 60-kw. somewhat less. The load is a perfectly steady one, so that from the power-house standpoint, such a furnace load is as desirable a load as could be imagined. On furnaces that are operated on 24-hour-day schedule, the load factor approaches nearly 100 per cent.

The earlier Ajax-Wyatt furnaces have now been in commercial use in Bridgeport Brass Company mills for a period of three years. This particular mill has now twenty-four of these furnaces in operation and the total output of these furnaces, since the first one was installed, is upwards of 100,000,000 pounds. So successful has been the use of this furnace in this particular mill that the old method of melting has been entirely abandoned.

In another mill twenty-four 60-kw. furnaces are in operation,

in another sixteen 60-kw. furnaces, etc. The total tonnage of brass melted *per day* in the furnaces already installed and under construction approximates 1,500,000 pounds.

The amount of brass melted per kilowatt hour is from seven and one-half to eleven pounds, depending on the power input of the furnace, and the nature of the charge.

The theoretical figure as determined by the United States Bureau of Standards, and other competent authorities, is given at twelve and one-half pounds per kilowatt hour. This figure is based on melting two-to-one yellow brass, and bringing it to a proper casting temperature, 2000 degrees F.

In continuous melting with the 60-kw. furnace, and taking the kilowatt hours used from Monday until Saturday, and dividing into the number of pounds charged, the week-in and week-out melting rate is shown to be eleven and one-quarter pounds per kilowatt hour, indicating an efficiency of 90 per cent. This leads one to doubt the theoretical figure.

A brief summary of the cost of operation of the Ajax-Wyatt furnace as compared with the old style " Pitt furnace " can be made in the following short statement:

REPAIRS: Repair cost on electric furnace no greater than repair cost on pit furnace.

POWER: The cost of electric power as compared with hard coal fuel is practically the same.

SAVING: In addition to the above there is a great saving on labor and crucibles are entirely eliminated. Metal loss is reduced to an average of under 1 per cent., and from 5 to 10 per cent. more metal goes into production instead of scrap. This total saving amounts, very conservatively, to $\frac{1}{2}$ cent per pound on the metal melted.

In addition to the above actual savings, there is produced a better quality of brass because of the perfect control of mixture and heat treatment, thus causing a minimum of rejections. Also, there is a decided bettering of the working conditions, an advantage which cannot be directly expressed in dollars.

In the Ajax-Wyatt furnace has been found for the first time a satisfactory device capable of replacing the ancient crucible and pit furnace. Its use in the brass mills in the country is extending with remarkable rapidity.

The Ajax-Wyatt furnace is made in two general types. One

tilting upon a central trunnion (Fig. 20) and another tilting with the pouring spout as the centre of oscillation (Fig. 21). This latter type of furnace is, of course, counterweighted for ease of manipulation. It is the latter type that is now used exclusively in the brass mills, because it permits of very satisfactory direct

FIG. 20.
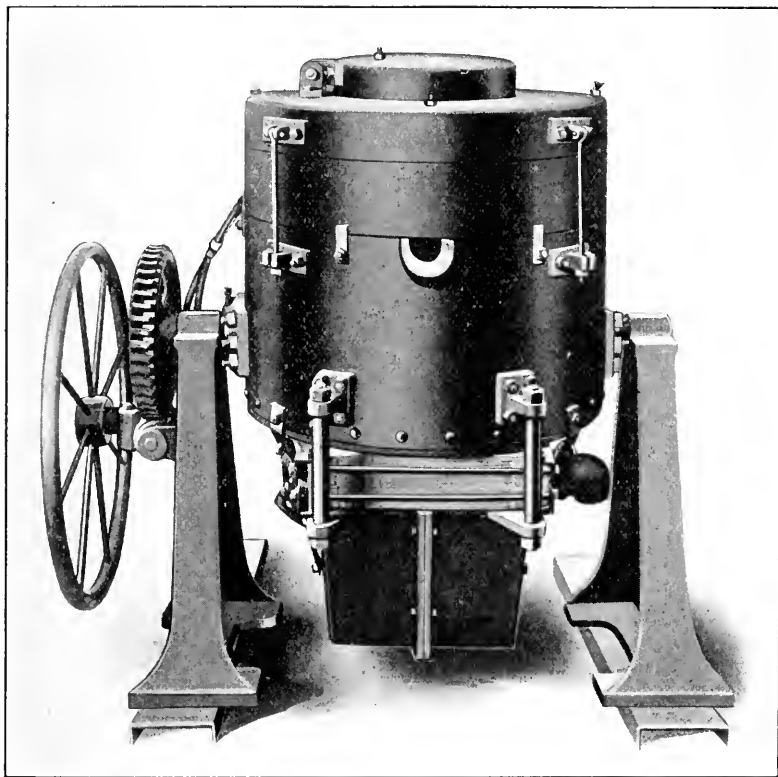
Ajax-Wyatt furnace of the central trunion tilting type. This is a type of furnace used for pouring metal into a ladle and from the ladle into molds.

casting into molds. This feature, from a practical standpoint, is one of decided importance.

A modified method of tilting is used on the battery of furnaces shown in Fig. 22.

Having now described one form of furnace, in the development of which I have been interested, I will describe another, a

more recent development. I refer to the invention of Dr. Edwin F. Northrup, of Princeton University.

The Ajax-Wyatt form of furnace operates directly upon

FIG. 21.
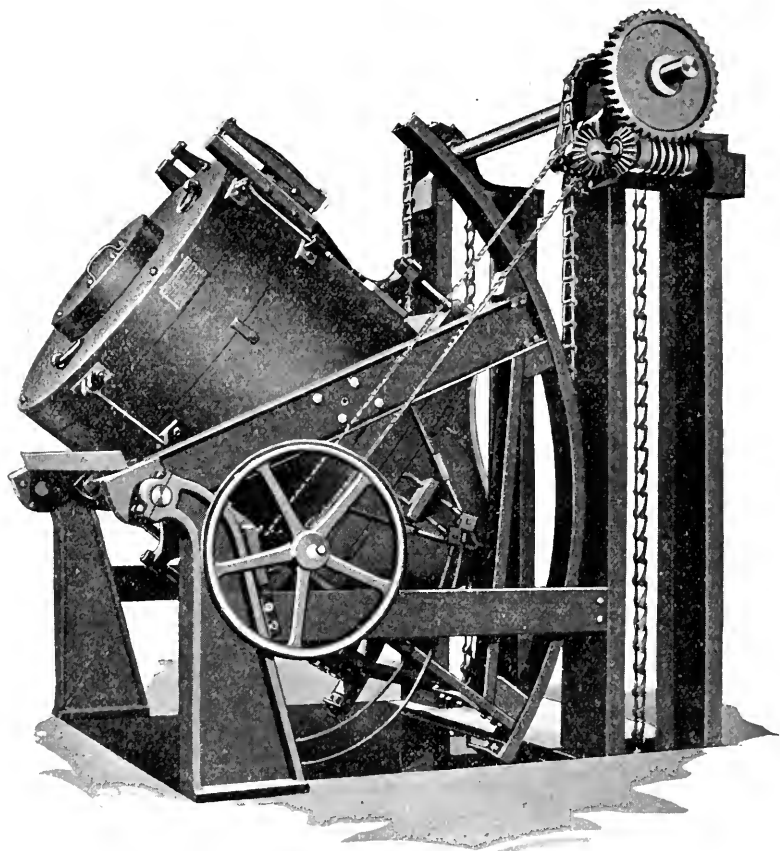
Ajax-Wyatt furnace having pouring spout as centre of oscillation. This type of furnace is exclusively used in brass mills. This method of tilting permits cf very satisfactory direct pouring into moulds. This feature, from a practical standpoint, is one of decided importance.

existing circuits, 25 or 60 cycle. The power factor, as I have stated, is as high as 85 on the usual 60-cycle circuit.

Doctor Northrup has succeeded in developing a commercial furnace of satisfactory power factor, using currents of relatively high frequency, namely 10,000 to 12,000 cycles per second. When currents, having frequency of the magnitude stated, are

used, splendid inductive effect is possible without interlinkage
of magnetic circuit. It therefore becomes possible to heat a body
of conducting material contained within the walls of a plain cylin-
drical form of hearth or crucible. No resistor column of molten-
conducting material is necessary. Because of this fact, this
furnace has a far greater degree of flexibility in its operation than
is possible in any other form of induction furnace. For example,
it is possible to completely melt the full contents of the hearth,

Fig. 22.
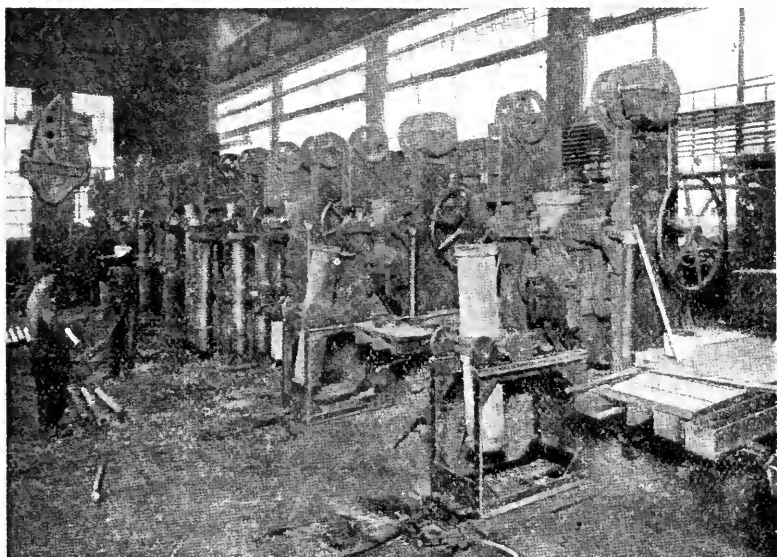
Battery of furnaces at the Bridgeport Brass Company showing a modified method of tilting
designed by that company.

then entirely discharge its contents and recharge with solid mate-
rial. It thereby becomes possible to change from one mixture to
another without inconvenience or shut down. In fact, the furnace
has all the flexibility of operation common with the ordinary
crucible-type or fuel-fired furnace.

It has been found most convenient and satisfactory in the
construction of furnaces under 20-kw. per phase, with a maximum
therefore of 60 kw. on a three-phase circuit, to use as a source
of high-frequency current, oscillatory discharge of a bank of
condensers. By properly proportioning the capacity and induc-

tances of the oscillatory circuit, the desired frequency is obtained. A 60 cycle line current may be supplied at the existing voltages. A transformer steps this e. m. f. up to 8000 volts. A bank of condensors is discharged at this voltage and upon rupture of

FIG. 23.
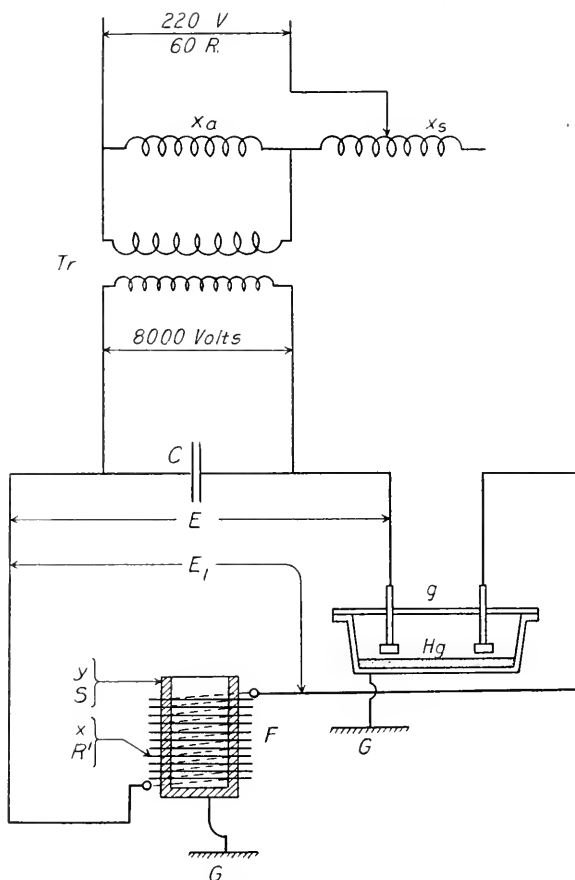
Oscillatory current system invented and designed by E. F. Northrup for producing high frequency oscillatory currents.

the spark-gap oscillations occur (Fig. 23). The current with high-frequency oscillations passes through the inductor coil, which surrounds the crucible or mass to be heated.

This form of heating device, owing to its great simplicity and flexibility of operation and application, affords untold possibili-

ties. The high-frequency generator capable of producing an oscillatory discharge sets limitations upon the size of the heating units as previously stated to 20 kw. per phase, with power factor about 70 per cent. With a power-driven generator producing currents of pure sine wave form, the size within the commercial requirements is practically without limit.

Highly perfected generators are now on the market for wireless apparatus, and within a short time will very largely replace all static equipment in the larger stations. Such generating machines, however, are exceedingly expensive, in fact so expensive as to make their use prohibitive for heating. More recently a number of engineers have given their attention to a design of motor-driven generator to meet the demands for heating purposes. The progress already made is so very encouraging as to permit me to predict with almost positive assurance that a satisfactory generator of high-frequency current will very shortly be available at a reasonable price having one hundred or two hundred kw. capacity or multiples thereof.

Such generators are naturally of small, lightweight construction, revolving at a high rate of speed. The speed is of such magnitude that they may be driven by direct connection with a steam turbine. With the oscillatory system the furnace efficiency is about 40 per cent., and with the straight alternating current, delivered from a generator, 80 per cent., but as the generator efficiency is but 60 per cent., the ultimate efficiency is 48 per cent. The development of this type of furnace has been carried to a point that it now becomes available for many commercial operations. About 20 furnaces are in use in the most important industrial and scientific laboratories of the country, and some are filling commercial requirements in small sizes.

Three of these furnaces have recently been installed in the Philadelphia Mint for silver melting, also one at the plant of Handy and Harman, silver melters and refiners of Bridgeport, Conn. (Fig. 24), and two of them are in use by Mr. Edwin A. Colby at the Baker Platinum Works, in Newark, N. J., for melting platinum in a non-carbonatious atmosphere.

Thirty-two years have intervened since the time when Colby first gave to the world the induction furnace, and the time when he was able to secure an induction furnace that would meet his individual requirements. Thus is the fate of the inventor.

A comparison from the commercial viewpoint of these two

types of induction furnaces, namely the Wyatt and the Northrup, from our present knowledge and viewpoint, is as follows:

The Wyatt furnace is the most efficient electrical furnace as yet developed. The efficiency is so high that further improve-

FIG. 24.
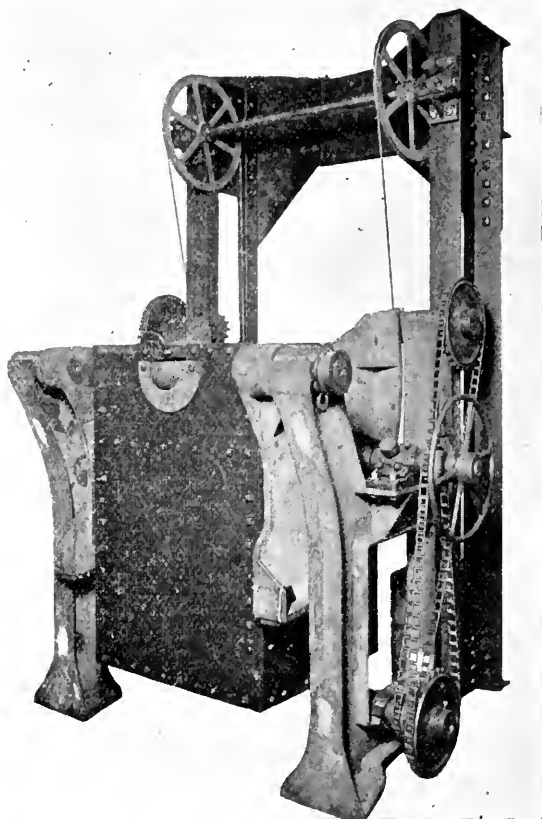
Ajax-Northrup high frequency induction tilting furnace in use for silver melting at the plant of Handy and Harman, Bridgeport, Conn.

ment in this direction can be but trifling. It is exceedingly simple in construction and operation. Its electrical characteristics are of the best, and power factor of 80 per cent. is considered quite satisfactory by power companies. As at present developed, it is for single-phase operation, but satisfactory two- or three-phase furnaces will no doubt be developed in the future.

If a sufficient number of furnaces are in use to balance the phases, namely two furnaces or multiples of two on the two-phase line, and three furnaces or multiples of three on the three-phase line, the load is entirely balanced.

Small furnaces give greater flexibility of operation, but the first cost is naturally higher if two or three times the power were used in a single unit. As a portion of the charge must always remain in the furnace, it is not practicable to frequently change from one mixture to another. Furthermore, as a liquid charge is necessary for starting, it is not a furnace that can be conveniently started. It is a furnace, therefore, which should be used for 24 hours per day operation, or if used for intermittent operation, a sufficient amount of current should be kept on to supply the heat losses. This on a 60-kw. furnace is about 8 kw.

A further limitation has been put on the furnace in confining its field to melting alloys low in lead, because high lead alloys penetrate the lining material. With improved methods of lining, and a more satisfactory lining material, this drawback will also be overcome. Recent experience in this direction is very promising.

The Northrup furnace, as before stated, can be more conveniently used in intermittent service than any other furnace thus far developed. As the refractory material used is an absolute minimum in quantity, the first heat of the furnace can be taken off with almost the same rapidity and efficiency as the second, there being no great mass of refractory material to be first heated, as in other furnaces.

It is not believed that this type of furnace, because of its lower efficiency and greater cost of installation, owing to the intermediate high-frequency generator that must be used, can hope to compete with the Wyatt furnace in performing in the class of service for which this furnace is particularly applicable.

Its field will be for intermittent melting, or very high temperature melting such as required for " alloy steels," ferro alloys, precious metals, metallurgical operations, high temperature heat treating, etc.

Remarkable progress is being made in the application of electricity for heating purposes of all kinds, but as yet we have hardly scratched the surface.

Plant Fibre Paper. (*Forest Products Laboratory, News Note.*)
—The laboratory receives frequent requests for information regarding the possible use of plant fibres, such as sugar-cane bagasse, corn stalks, cotton stalks, the various straws, etc., for pulp and paper manufacture.

The laboratory is restricted in its investigations to a study of the best means of utilizing our forests and forest products, so that little work has been done on the pulping of these plant fibres. From general experience, however, it is believed that these various fibres are not economical for pulping under present American conditions, as they offer the following difficulties in handling:

1. Plant stalks, straws, grasses, etc., usually contain a large percentage of pith, giving pulps low in fibre content and requiring high chemical consumption.

2. Material of this type represents seasonal crops, so that facilities must be provided for the storage of a large volume of the stock in order to permit the paper mill to operate throughout the year. The susceptibility of such material to decay adds greatly to the costs and difficulties of storage.

3. Due to the bulkiness of these materials, the digester charge is reduced, thereby reducing the yield and increasing overhead costs proportionately.

Some of these fibres, such as the straws, are being pulped at the present time for use in the manufacture of corrugated board and cheaper board products. Pulp of this nature, however, does not compare with a refined pulp such as sulphite or rag stock; it can be used only for special purposes and not in the manufacture of newsprint or high-grade paper. Plant fibres of this nature are being reduced commercially in Europe where economic conditions and the scarcity of wood permit their utilization. But under present American conditions, it is believed that such fibres can not compete commercially with wood pulp.

Salt. (*U. S. Geological Survey Press Bulletin 455*, August, 1920.)—The volume of the salt in the ocean is enough to cover the entire surface of the United States to a depth of 8500 feet.

Heats of Combustion of Organic Compounds.—THEODORE W. RICHARDS and HAROLD S. DAVIS, of Harvard University (*Journal of the American Chemical Society*, 1920, xlii, 1599–1617), have determined the heat of combustion of the following compounds. The results are expressed in 18° calories per gram of substance weighed in a vacuum: Sucrose, 3943; benzoic acid, 6320; naphthalene, 9614; benzene, 10014; toluene, 10155; tertiary butyl benzene, 10434; cyclohexanol, 8882; di-isoamyl, 11339; methyl alcohol, 5326; ethyl alcohol, 7101; prophyl alcohol, 8033; butyl alcohol, 8615; isobutyl alcohol, 8599.   J. S. H.

U. S. ARMY SEARCHLIGHTS.*

BY

CHESTER LICHTENBERG.

Captain of Engineers, U. S. Army.   Member of the Institute.

FOREWORD.

1. Artificial illumination has been used in military opera-
tions as far back as written historical records are available.   The
story of Gideon and his three hundred lamp-bearers has been
handed down from Biblical times.   The use of Greek fire by the
ancients is well known to students of history.   In the same man-
ner the unique employment of searchlights during the World War
will undoubtedly be recorded in the story of nations.

INTRODUCTION.

2. Searchlights are relatively simple.   They consist of some
form of mounting, which holds a reflector and the source of
light.   They are usually provided with a supply of energy from
an external reservoir or generator.   They are used for the loca-
tion and illumination of targets, for beacons and for signalling.

MOUNTINGS.

3. The mountings of searchlights furnished prior to 1918
followed the same general scheme.   They consisted of a barrel
or drum, hung on trunnions in a yoke supported by a base.   Fig. 1
shows a typical drum-type searchlight.   It is a 60-inch size and
intended for permanent emplacement in coast-defense positions.
It weighs 6600 pounds.   The drum is made of sheet steel.   The
sides are pierced with suitable openings to accommodate the arc
mechanism, arc viewing screens, arc regulators, etc.   The rear
of the drum is closed by the mirror back.   The front of the drum
is closed by plate-glass strips.   The trunnions permit movement
in a vertical plane.   The yoke is pivoted to the base and permits
movement in a horizontal plane.   The combination allows the
searchlight beam to be directed at any target within 360 degrees
of azimuth and 240 degrees of elevation.   The base serves two

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* Communicated by the Author.

functions. It acts as a foundation for the drum and provides a shelter for any distant training mechanism.

4. Mountings underwent a startling change in 1918 and 1919. The pre-war searchlights, with very few exceptions, were heavy
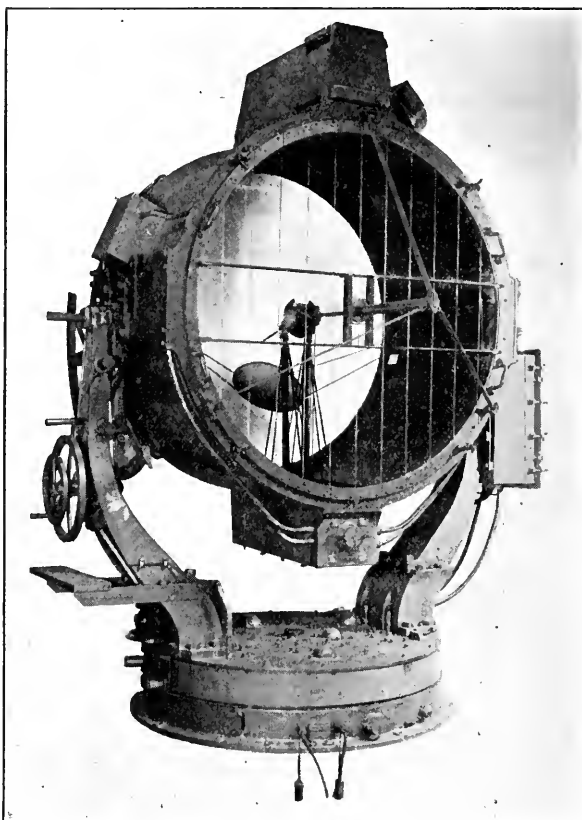
Sixty-inch, 150 ampere, high intensity arc, barrel type of searchlight, typical of design used for coast defense emplacements.

and immobile. The design was first modified to meet mobile army requirements. The heavy base (Fig. 2) was replaced by a four-wheeled carriage (Fig. 3). This was an important minor modification. It permitted manufacturers to supply practically standard equipment, for the production of which they had a full set of tools. One hundred and eighty (180) of these units were

ordered late in 1917. Shipments of them were started to France in the spring of 1918. They formed a portion of the searchlight equipment of the First and Second Armies, A. E. F., and made a splendid record on the Western Front.

5. The placing of 60-inch drum searchlights on wheeled bases

Fig. 2.
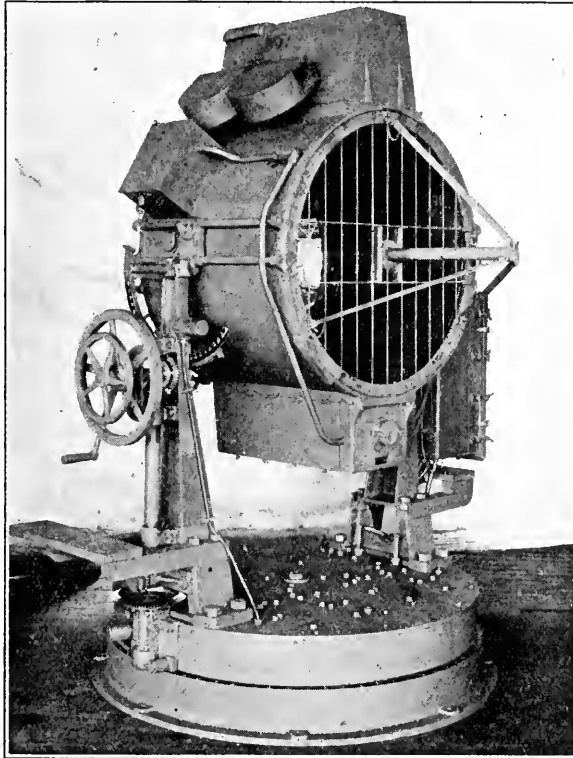
Thirty-six-inch, 150 ampere, high intensity arc, barrel type of searchlight, typical of the design formerly used in coast defense emplacements.

was considered at the time the 36-inch model was developed. The standard 60-inch drum, trunnions and yoke were, however, too heavy and tall to permit making them mobile by the substitution of a wheeled base for the standard stationary base. As a first solution the standard equipment was arranged as shown in Fig. 4. This was an assembly of available units in order to provide a semi-

portable equipment for immediate service in France. Only a few of these units were built, because they were relatively heavy and costly and could only be moved at relatively low speeds and then with difficulty. They illustrated, however, the tendency to promptly provide the American Expeditionary Forces in France with matériel required for military operations.

FIG. 3.
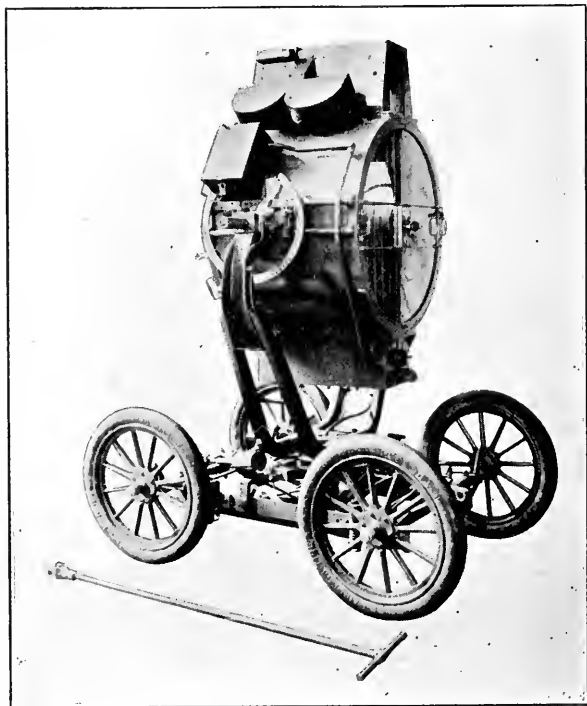
Thirty-six-inch, 150 ampere, high intensity arc, barrel searchlight, mounted on wheeled base and typical of the type used by the A. E. F. in France.

6. The problem was next presented to searchlight manufacturers. They studied it for a short time and then proposed building light-weight drums, supports and carriages. One manufacturer used aluminum in every practicable place. The result is shown in Fig. 5. The searchlight complete weighs 2300 pounds. It represents the practical limit of this method of design. It has an automatic mechanism and all of the other features of the 1917

model (Fig. 1), excepting distant electrical training control. However, it is infinitely more mobile. It is shown in Fig. 6, arranged for lorry transportation.

7. Another 1918 design of 60-inch light-weight drum is shown in Fig. 7. In this design new methods were devised for making and supporting the component parts. It weighed 2200 pounds. It had an automatic arc feeding and regulating mechan-

Fig. 4.
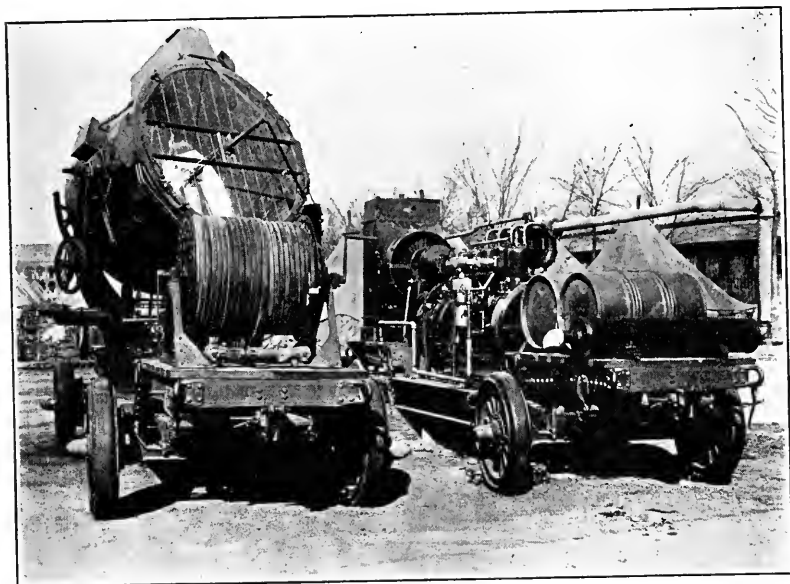
Sixty-inch, 150 ampere, high intensity arc, barrel type of searchlight and 125 volt 25 kw. gasoline-electric generating set, mounted on trailers, typifying equipment designed for mobile army.

ism and besides was equipped with a new design of distant electrical training control. It was in every way the equal of the 1917 model designed for fixed emplacements, in addition to which it was *mobile*.

8. About the time the design of the light-weight barrel searchlights was projected, a representative of the A. E. F. was returned to the United States. This officer was Major Richard Wheatly Lewis, Engineers, who, at that time, was a captain in the 56th Engineers. He was instructed by Lieut.-Colonel John C. Gotwals, Commanding Officer of the 56th Engineers, to con-

fer with the Engineer officers in the United States and to present
to them the problems which had arisen in connection with the
operation of searchlights in the field in France. Major Lewis

FIG. 5.
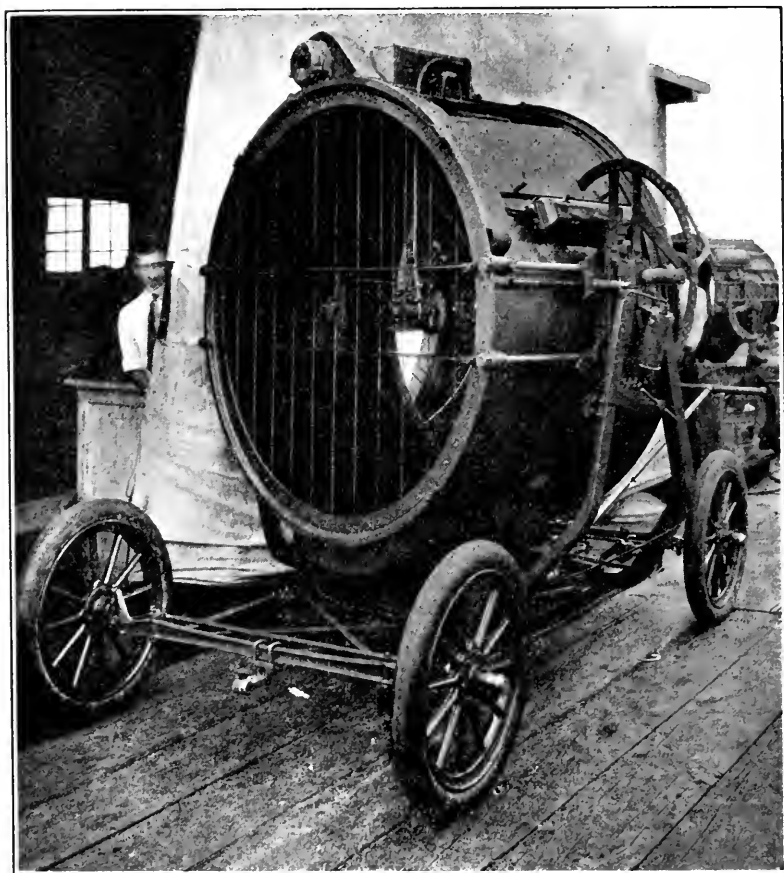
Sixty-inch, 150 ampere, high intensity arc, light weight barrel type of searchlight, on wheeled
base, illustrating minimum practicable weight for this design.

had exceptional opportunities for observing the requirements, and
besides was gifted with a unique synthetical mind, which enabled
him to make a very remarkable suggestion. In April, 1918, he
sketched what has since been known as the open-type searchlight.
In May, 1918, the first model was built at Ellington Field, Texas.

Fig. 6.
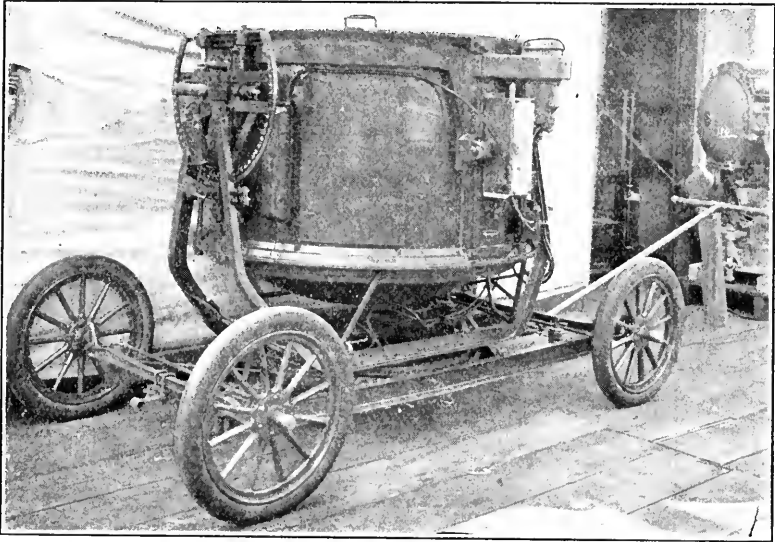
Sixty-inch, 150 ampere, high intensity, light weight barrel searchlight, arranged for lorry transportation.

Fig. 7.
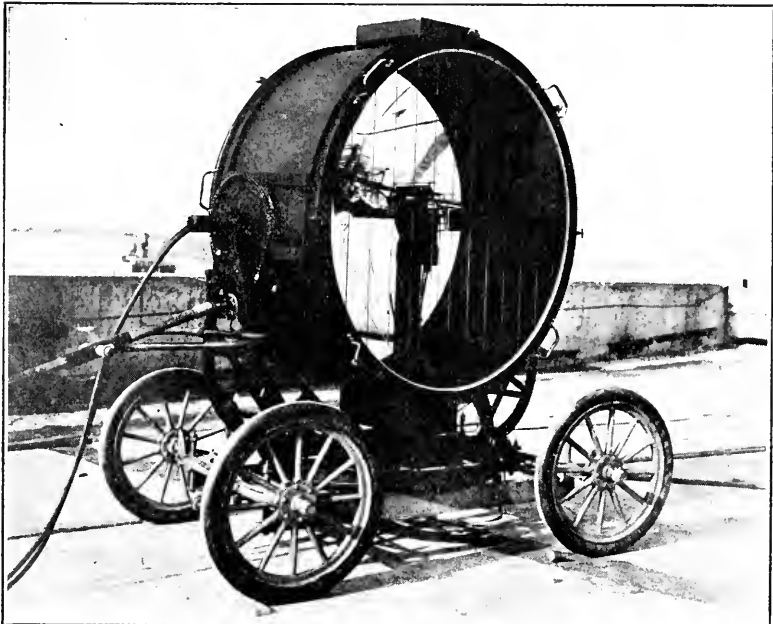
Sixty-inch, 150 ampere, high intensity arc, wheeled light weight, barrel searchlight, illustrating second design to give maximum power with minimum weight.

It was a 36-inch design. It is shown in Fig. 8. It consists essentially of the mirror and mirror back of a 36-inch barrel searchlight hung in trunnions, with the automatic high intensity

Fig. 8.
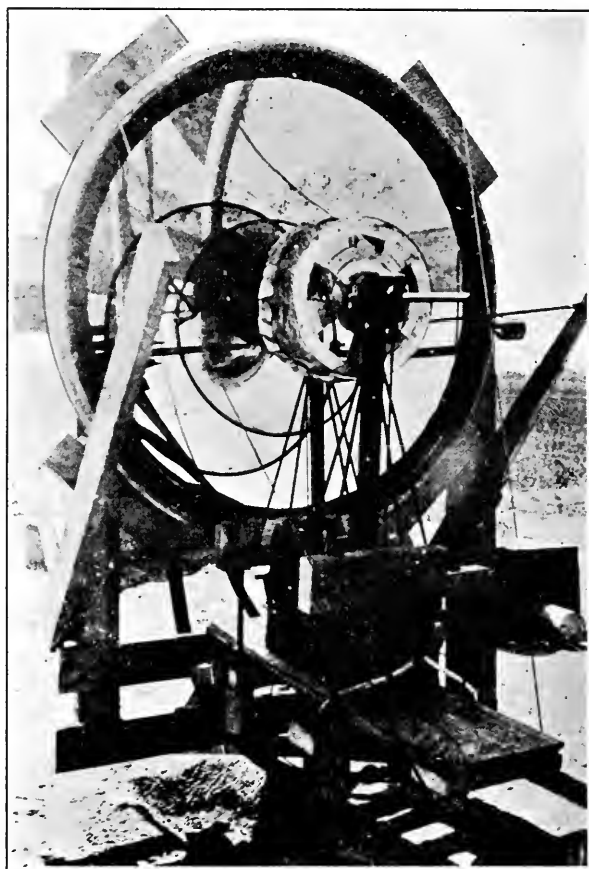
First model of open type searchlight. It has 36-inch glass mirror and 150 ampere high intensity arc mechanism.

mechanism of the same light supported in front of the mirror. The carbon points were protected from wind currents by a tin shield which, at the same time, minimized stray light. This model was operated at Ellington Field for about a month and proved very efficacious.

9. The suggestion of the open-type mounting was immediately followed by the presentation of the idea to searchlight manufacturers. They were requested to consider its possibilities and to immediately develop models which could be manufactured in quantity and shipped promptly to the A. E. F.

10. One of the first commercial developments of the open-

Fig. 9.

First commercial open type searchlight. It has 60-inch mirror and 200 ampere medium intensity arc mechanism.

type searchlight is shown in Fig. 9. It was designed and built about June 15, 1918. It was subjected to close scrutiny, which indicated a number of minor improvements. These had in view a reduction of weight, an increase in rigidity and an increase in mobility. The result of these suggestions was the design and building of the first practical commercial open-type searchlight which was exhibited June 28, 1918. It is shown in Fig. 10. The mounting consists essentially of a rigid triangular base, provided with axles and wheels. The turntable and yoke are mounted

above the triangle. The mirror ring and trunnions are set in the yoke. Ribs from the mirror ring to a central breech form a holder for the mechanism. The arc mechanism is of cartridge type and is held in the breech at a suitable position. The mirror is supported in the mirror ring in the usual fashion.

11. In order to facilitate production, representatives of the Army Engineers and the manufacturers met in Washington in the summer of 1918 and completed a so-called standard Army

FIG. 10.
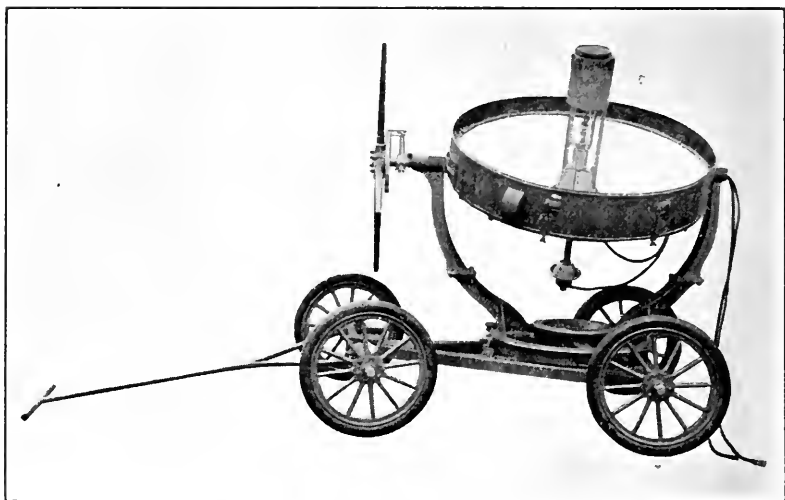
Second commercial design of open type searchlight. It has three point suspension, rigid frame carriage and stray light shield surrounding the mirror.

design of carriage and mounting. With minor modifications, a large quantity of these were built by the manufacturing companies. Representative types are shown in Figs. 11 and 12. They enabled standard running gear to be used. These could be obtained in quantity and thus permit rapid delivery. They used a relatively light-weight turntable, yoke, mirror ring and trunnions and were so designed as to permit of manual distant training.

12. Early experience with a few of the mountings shown in Figs. 11 and 12 indicated that a marked saving in weight could be effected if special parts, instead of standard parts, were used. Several models were designed and built. These are shown in

Figs. 13, 14 and 15. Complete with searchlights, they weigh less than 1000 pounds. They are so designed as to permit various portions to be readily removed. The running gear is easily taken off. The mechanism can be taken out of the breach by one man. The mirror ring with the mirror can be lifted out of the yoke

FIG. 11.

Sixty-inch open type Army design searchlight with 200 ampere, medium intensity arc mechanism, similar to design standardized and used by the A. E. F. in France.

by two men at the trunnions. The result has been the development of a very light-weight mounting, capable of being rolled over the ground to the point of emplacement and there rapidly dismantled, emplaced and assembled.

13. Another result of the intensive study of 60-inch wheeled mountings and litter mountings which have been described was the development of a very light weight, small diameter mirror

type of searchlight, mounted on a tripod. This was designed
with a view of providing a very portable equipment, which could
be placed in otherwise inaccessible places. For example, it is
often advantageous to locate a searchlight on top of a tower or
in a church belfry or in the top of a tree. The 60-inch designs
are too heavy to permit of such installation. However, the

FIG. 12.
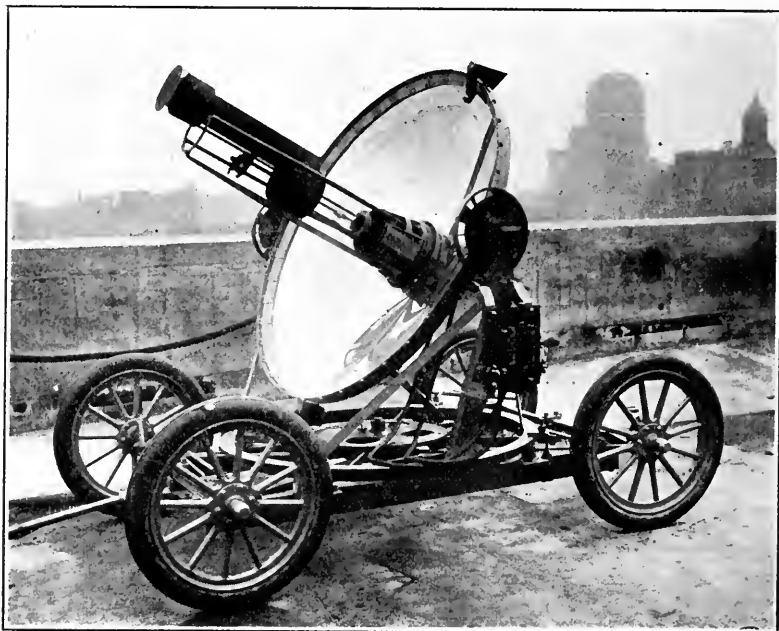
Sixty-inch open type Army design of searchlight, with 150 ampere high intensity arc lamp
mechanism, typifying design used by A. E. F. in France.

30-inch designs, shown in Figs. 16 and 17, are admirably adapted
for this sort of installation. They are each provided with 30-inch
glass mirrors, hand-operated, high-intensity arc mechanisms and
the usual complement of adjusting scales, stray light shields,
finders, etc. They are unusually efficient at ranges up to 15,000
feet. The designs illustrated take the same sizes of carbons as
do the 60-inch high-intensity designs and operate at the same
current and voltage; that is, 150 ampères, 75 volts. They weigh
only 225 pounds.

FIG. 13.
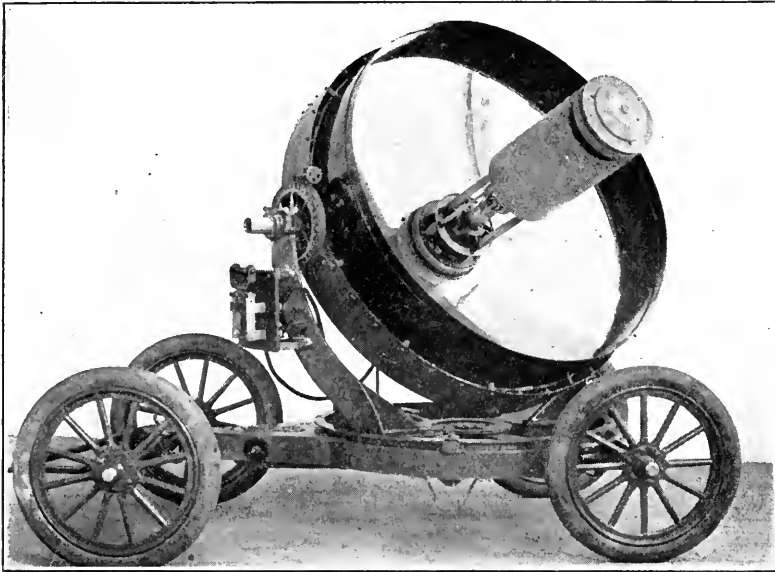
Late development of 60-inch open type searchlight, with 200 ampere medium intensity arc lamp mechanism, improved carriage, improved light shield on mirror and internal finder on mechanism.

FIG. 14.
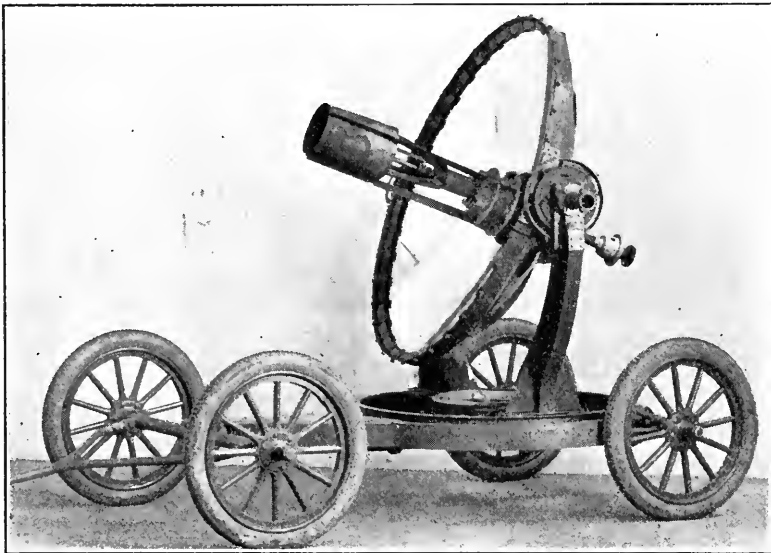
Early design of 500 ampere medium intensity arc lamp mechanism in open type searchlight.

MIRRORS.

14. The most suitable sort of mirror for use in a searchlight has been the subject of study for the last fifty or more years. The glass parabolic mirror with silver back was adopted by the United States Army about fifteen years ago. This type of mirror is the most efficient which has been developed. One is shown in Fig. 18 during a line test for figure. It has a reflec-

FIG. 15.
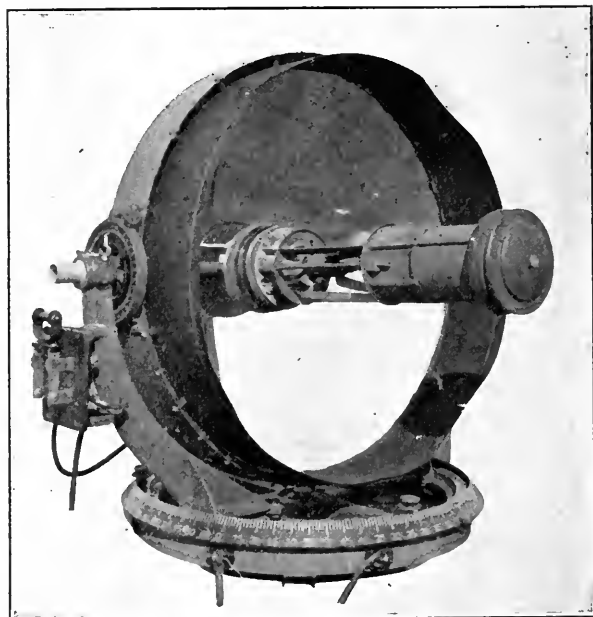
1920 design of open type searchlight, with 200 ampere medium intensity arc lamp mechanism, having internal finder. This equipment is typical of the design now being mounted on the portable towers.

tivity of about 95 per cent. and an almost perfect figure. It has, however, one very important limitation. Its manufacture requires from eight to fifteen weeks on account of the numerous and delicate processes through which it must go. It is also to a certain extent fragile, although a very wide experience indicates it to be very much less so than appearances would indicate. In fact, the records of the A. E. F. indicate only one mirror broken during transportation and only two mirrors broken by detonations.

15. The physical limitations in the production of parabolic glass mirrors resulted in a great deal of study being given to other methods of producing suitable searchlight mirrors. The

FIG. 16.
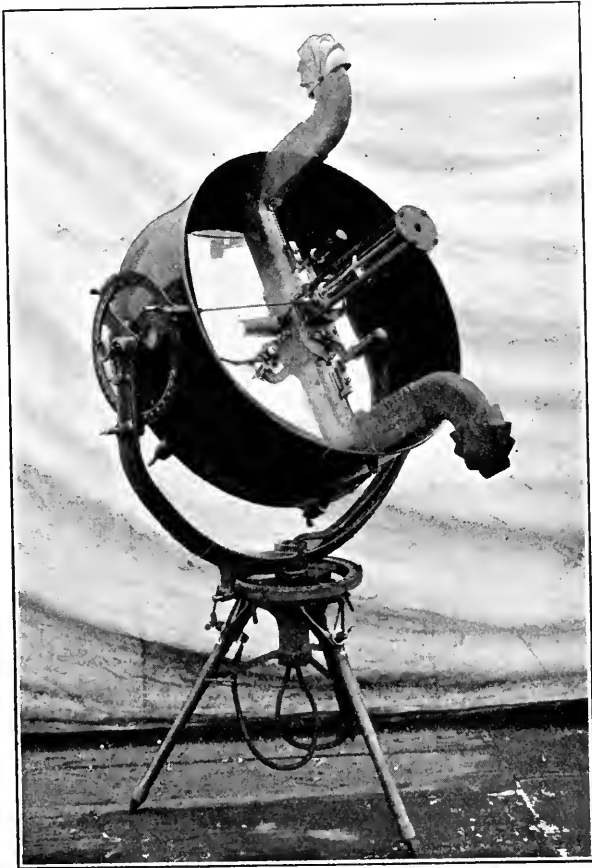
Thirty-inch open type searchlight with 150 ampere high intensity arc, hand feed mechanism, illustrating extremely light weight design.

literature on the subject was digested.   Eminent authorities were consulted.   Manufacturers were interested.   As a result, a relatively new method of mirror manufacture was started.   The glass portion of the silver-backed glass mirrors was used as a form.   Silver was chemically deposited on it in the usual manner.

Next the silver coating was backed with electrolytically deposited copper or copper and nickel. Then the silver surface and its backing were lifted from the glass form. The initial experi-

FIG. 17.
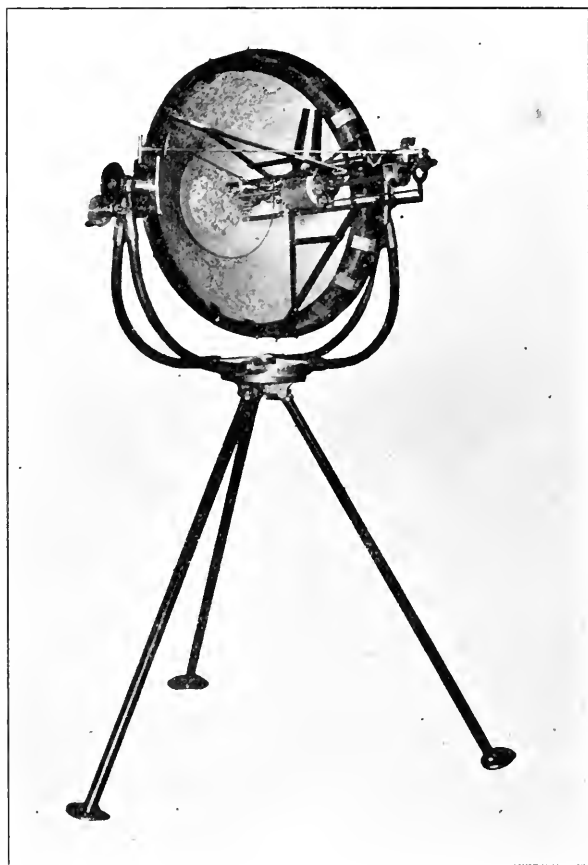
Another design of 30-inch open type searchlight with 150 ampere, high intensity arc, hand feed mechanism.

ments were unusually successful and gave great promise. Difficulty was experienced, however, in providing a suitable backing for the very thin film of silver. It was necessary that the backing be as rigid as glass, else the figure of the mirror would suffer. It was also necessary that the backing retain its exact shape and

not change due to temperature or moisture conditions. A great deal of experimental work was done, and there was developed prior to the November 11, 1918, armistice a method of manufacturing metal mirrors which enabled them to be produced at less than half the cost of glass mirrors and in about one-fifth the time. The metal mirrors had practically the same coefficient

Fig. 18.
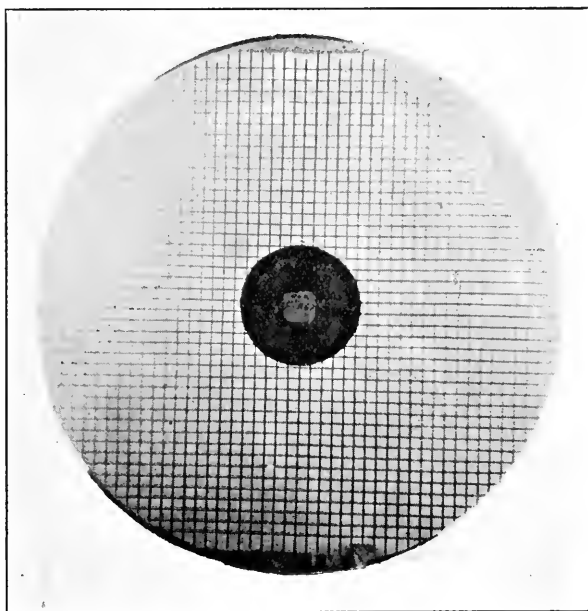
Photograph taken of a parabolic glass mirror, showing the accuracy of its figure. The lines in the photograph are reflections from parallel lines on a large screen held in front of the mirror. The photograph was taken from a point just behind the screen, the camera lense being pointed at the mirror through a hole in the screen.

of reflectivity as the glass mirrors and practically as good a figure. The silver surface was protected by a suitable gum varnish which retained its protective powers without deterioration for about four to six months. At the end of this time it was necessary to remove it by a solvent and then replace it by a new coating. The process of removing and recoating is simple and, with a little care, can be accomplished in the field. It in no way affects the reflectivity of the surface. Types of metal mirrors

developed in accordance with this process are shown in Figs. 19, 20 and 21.

MECHANISMS.

16. The mechanisms used for pre-war searchlights were complicated and delicate affairs, weighing 100 pounds or more. A typical one is shown in Fig. 22. It is basically an automatic mechanism for maintaining the correct distance between the car-

FIG. 19.
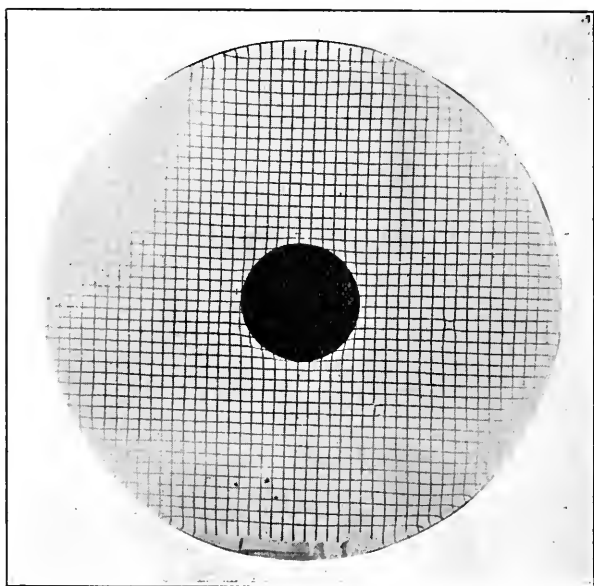
Reproduction of photograph illustrating line test of a silver metal mirror made by the deposition process and illustrating the accuracy of its figure.

bons and between the positive carbon crater and the mirror and for feeding them as they are burned away. In addition, the mechanism is so designed that the positive carbon is continuously rotated. This is done in order to make the crater of uniform shape. The mechanism performed its functions relatively successful. On account of the many parts which it contained, however, it was not well suited for mobile searchlights. In transporting it from place to place, many of the small parts fell out of adjustment, so that after reaching its destination and

Fig. 20.
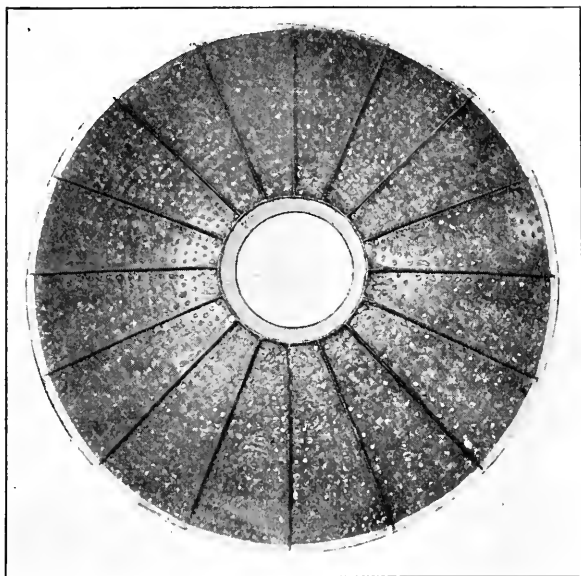
Ribbed sheet steel reinforcement for the cement backing of a metal mirror.

Fig. 21.
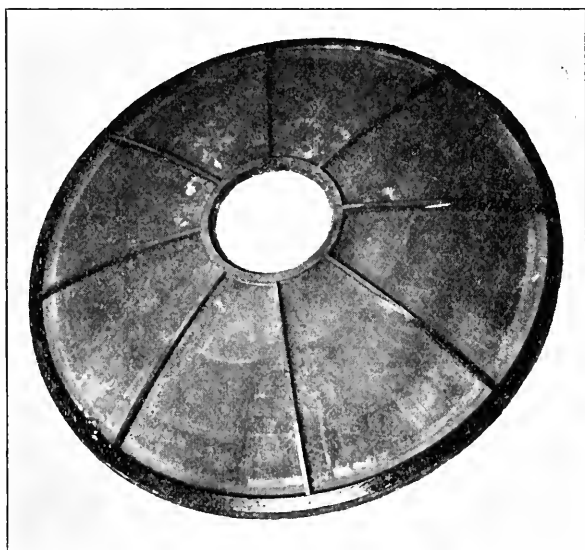
Spoke and rim design of reinforcement for a deposited silver metal mirror with copper nickel backing.

before it could be operated an inspection was necessary and frequently repairs, and always readjustments were required.

17. The need for a simpler mechanism, which would be more rugged and which would more successfully withstand the rigors

FIG. 22.
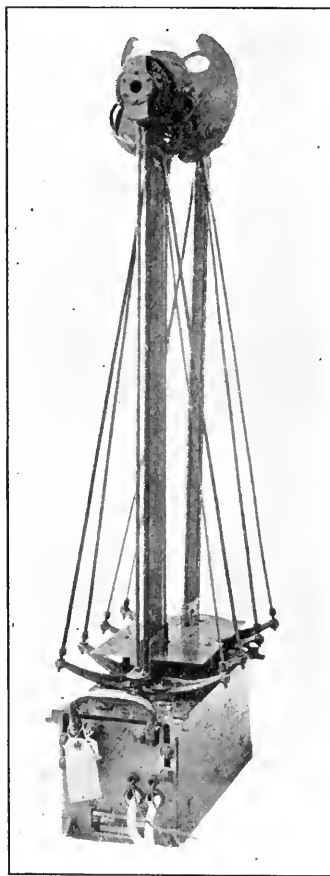
Automatic mechanism of 60-inch, 150 ampere high intensity arc searchlight.

of transportation, was soon evidenced. It was deemed practically impossible to promptly design an automatic mechanism which could take the place of the standard and be very much more rugged. Consequently, immediate steps were taken toward the design and production of a hand-fed mechanism. The design was

primarily based on the requirements of the open-type searchlight
shown in Figs. 8 and 9. This utilized a cartridge type of mechan-
ism which could be fitted into a breech block either from the
rear or from the front.

18. One of the early designs contemplated supporting the
entire mechanism from the mirrror ring by means of struts. A

Fig. 23.
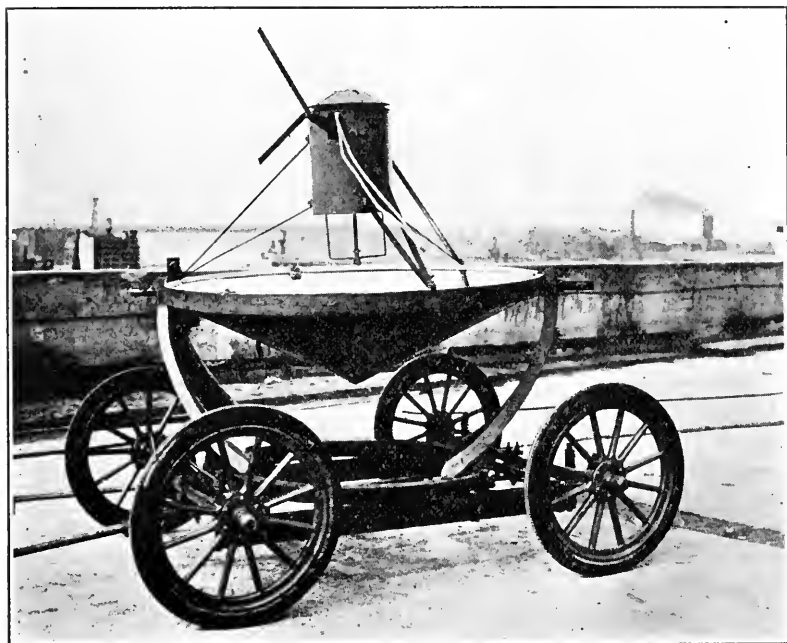
Mechanism and other details of an early design of 200 ampere, medium intensity arc
mechanism for open type searchlight, showing hand feed and method of supporting mechanism
from mirror ring.

sample of this mechanism, mounted in a searchlight, is shown in
Fig. 23. Another design used the cartridge principle. It had all
the principal parts located about a central axis. These were in
turn connected to an aluminum casting which fitted into the
breech block from behind. An early sample of this development
is shown in Fig. 24. This presented so many good features, par-
ticularly ruggedness and few parts, that it was adopted as one of
the standards. A few features of design were modified and the

rough edges polished off. A number of these units were then
ordered for the use of the A. E. F. A typical one is shown in
Fig. 25. It uses 28.5-mm. positive carbons and 16-mm. negative
carbons. A current of 200 ampères at 65 volts produces in this
mechanism what is known as a *medium intensity arc*. The entire
control is from the rear of the searchlight. One hand wheel
permits rotation of the entire mechanism, so as to adjust the arc
to the correct focal point. A second concentric hand wheel
permits rotating the entire mechanism, yet retaining the arc at
the focal point. A third concentric hand wheel permits the

FIG. 24.
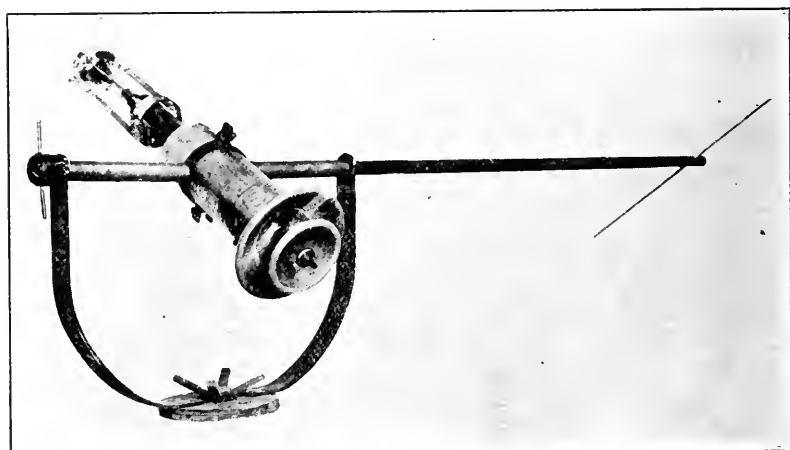
First design of cartridge type mechanism for 200 ampere medium intensity arc of open type
searchlight.

rotation of the negative. A fourth concentric hand wheel permits
feeding of the negative. A plug, concentric with the hand wheels,
acts as a switch as well as a current terminal.

19. Another form of cartridge mechanism is shown in Fig. 26.
It uses 16-mm. diameter positive carbons and 11-mm. diameter
negative carbons. It produces a *high-intensity arc* with 150
ampères at 75 volts. Unlike the previous mechanism, this one is
fitted into the breech block from the front of the mirror. The
controls, however, are at the rear of the mirror. One handle
rotates and feeds the positive. A second handle feeds the nega-
tive. A device is provided for giving small lateral adjustment
to the mechanism so as to bring the arc into the axis of the mirror.

The arc is maintained at the focal point by suitable feeding of the positive and negative carbons. Two positions along the axis of the mirror are provided so as to accommodate metal or glass searchlight mirrors.

Fig. 25.
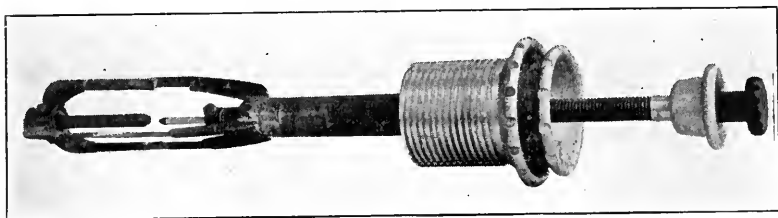
1918 design of 200 ampere medium intensity arc lamp mechanism, for 60-inch open type searchlight.

20. A further development of the cartridge searchlight mechanism has been in the direction of making the finder self-contained with it and providing the negative control with a flexible connection, so that the arc may be better guided with respect to the positive crater. A late design of such a mechanism is

Fig. 26.
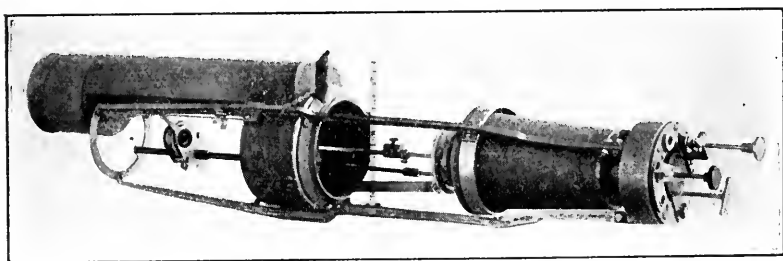
1918 design of 150 ampere, high intensity arc lamp mechanism, for 60-inch open type searchlight.

shown in Fig. 27. It has a self-contained finder, which is located very close to the control hand wheel. Otherwise, it is substanially the same as the cartridge mechanism shown in Fig. 25.

21. A radical redesign in mechanisms for barrel searchlights has recently been undertaken. One form of development has substituted aluminum in place of bronze or cast iron. In addition, the redesign has included making the pillar for supporting the carbons very much stiffer. As a result, the positive crater

is held rigidly in position. One form of such mechanism is
shown in Fig. 28. It is automatic in operation. It has a single
electric motor for operating the forced draft ventilation and the
mechanism feeds. Another form of mechanism which differs
radically from the preceding is shown in Fig. 29. It has resulted
from a close study of the cartridge mechanism and from the
advantages which this mechanism developed. It is automatic
in its operation and besides has the positive carbon automatically
rotated. It uses a single motor for the mechanism feeds and the
barrel ventilation.

FIG. 27.
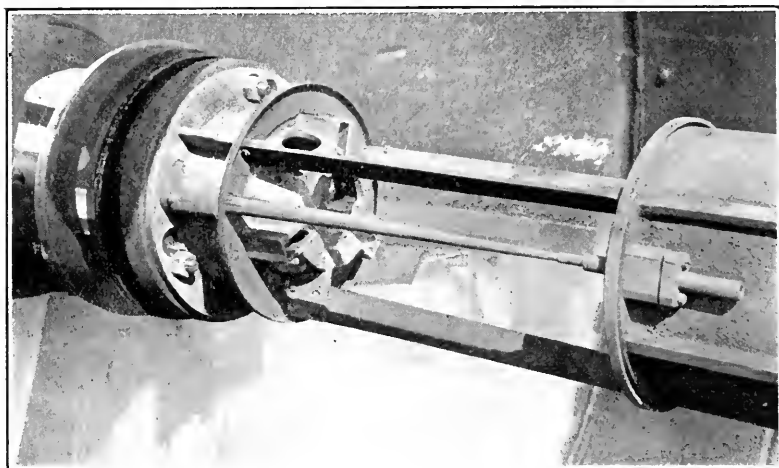
1919 design of internal finder for open type searchlight mechanism.

LIGHT SOURCES.

22. Light sources for searchlights have been the subject of
a great deal of study. Flames, incandescent solids and electric
arcs have been examined. The flames of all kinds are so large
that they cannot readily be placed at the focus of the mirror and
do not give a nice clean-cut beam of relatively small divergence.
Besides, their temperature is low and the amount of light which
they give per unit of energy input is relatively small. In addition,
it is difficult to maintain them and they are very sensitive to air
disturbances. Incandescent solids, particularly in the form of
the incandescent or glow lamp, are very fascinating light sources

for a searchlight. They require no adjusting. They operate throughout their life with practically uniform brilliancy. They are easily replaceable. They are relatively rugged. However, they have the very grave objection that the most efficient designs are only about one-third as efficient as the high-intensity arcs,

Fig. 28.
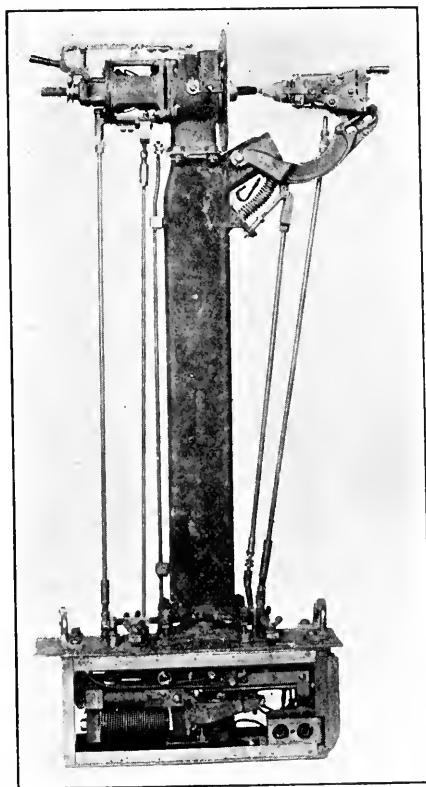
1919 design of light weight mechanism for 150 ampere high intensity arc barrel type of searchlight.

and besides, up to the present time, it has been impracticable to make them in commercial units larger than 3000 watts.

23. Electric arcs seem to have given the best kind of service for searchlights. They are relatively simple and enable a large flux of light to be concentrated in a relatively small area. As a result, an electric arc may be placed at or near the focus

of a reflector or mirror and produce, in combination with the mirror, a searchlight beam of relatively small divergence and high illumination.

24. Searchlight arcs may be divided into three classes, known, respectively, as low intensity, medium intensity and high intensity.

FIG. 29.

1919 cartridge design of 500 ampere, medium intensity arc mechanism, for light weight barrel searchlight.

The low-intensity arc is the ordinary one, such as was formerly used for street illumination. It operates with about 0.3 amp./sq. mm. of crater area. It gives a relatively yellow light and operates at a maximum temperature of about 3500° C. abs. Medium-intensity arcs have been a recent development. They are arcs taking practically the same electrodes as the low-intensity arcs, but with the current pushed up to the practical

limit of quiet operation. Such arcs operate with a current density of about 0.6 amp./sq. mm. and a maximum temperature of about 4500° C. abs. They give a brighter light than do the low-intensity arcs. They are distinctly more yellow and have in them more of the blue and violet, although this is not readily discernible.

25. A modification of the plain carbon arc is the so-called magnetically controlled arc. Various forms of the control have been devised and tried from time to time. The simplest form is one which carries current parallel to the carbons and produces a flux which steadies the arc stream. The arc with magnetic control is a bit brighter than the plain medium-intensity arc, but is not nearly so bright as the high-intensity arc. It operates at an approximate temperature of 4800° C. abs.

26. The high-intensity arcs differ from the low- and medium-intensity arcs in that the illumination comes from an incandescent globule of gas held in the crater (Fig. 30-B). This gas has a maximum temperature of about 5500° C. abs. The light given from a high-intensity arc is distinctly white, with a bluish tinge. It has remarkably great concentration of light flux, even when compared with the low-intensity and medium-intensity arcs. It represents the most efficient form of artificial light-producing source which is known.

27. The stability, steadiness and color of searchlight arcs are all of relatively great importance. Stability is given to an arc by a proper proportioning of the electrodes and by a suitable ballast resistance in series with the arc circuit. Steadiness is given by uniformity of flux in the neighborhood of the arc stream, homogeneity of the electrode materials and by a steady source of power supply. Color is primarily determined by the current density at which the carbons are operated or, in other words, the maximum temperature at which they are operated.

CARBONS.

29. Carbon has been found to be the most suitable material out of which to fashion the electrodes for searchlight arcs. This is due to its well-known high-temperature resisting qualities. Carbon for searchlight electrodes varies through a very wide range of characteristics. It may be hard or soft. It may be uniform in texture or mixed. It should preferably be of uniform

texture and either hard or soft, depending upon the type of arc which is to be maintained.

30. Medium-intensity and low-intensity arcs usually have electrodes with hard carbon shells and medium or soft carbon cores. The cores are provided in order to assist in centring

FIG. 30-A.
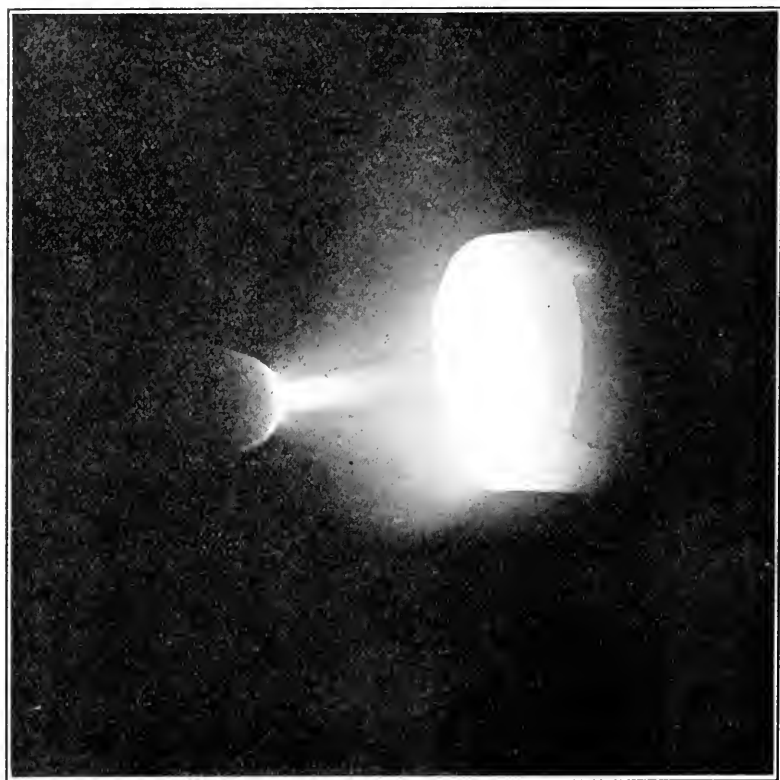
200 ampere, medium intensity arc, typical of those used in open type searchlights. Arc uses 28.5 mm. diameter positive carbon and 16 mm. diameter negative carbon.

the arc and forming the crater. The ratio between shell diameter and core diameter varies, depending on the current density of the crater. For low-intensity and medium-intensity arcs, it may be as high as 5 to 1. For high-intensity arcs, it depends on the character of the core material. High-intensity arcs are usually maintained between carbon electrodes provided with cores of

special chemicals.   These use various compounds of the cerium
family or group.   The composition of the core assists in forming
the gas globule which, when heated to incandescence, gives the
high-intensity arc characteristic.

31. Low-intensity and medium-intensity carbons may or may

FIG. 30-B.
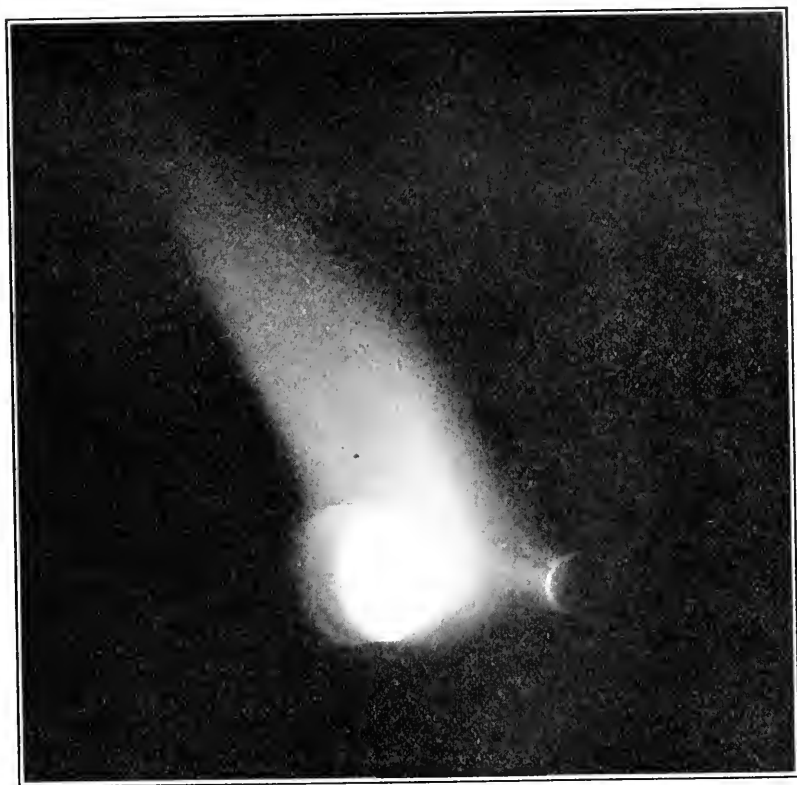
150 ampere, high intensity arc, typical of those used in open type and barrel type of searchlights.
Arc uses 16 mm. diameter positive carbon and 11 mm. diameter negative carbon.

not be copper plated, depending on the form of electrode core
and the current supplied to them.   Where the carbons are held
at the ends and where the current is high, copper plating is neces-
sary in order to carry the current along the carbon without heat-
ing it and causing spindling.

32. The crater formed in a carbon is important with regard

to the light-giving power of the arc established. The crater of low-intensity and medium-intensity arcs should be preferably dish-shaped, while the crater of high-intensity arcs should be preferably cup-shaped. The material used in the manufacture of carbons and the skill displayed are of prime importance in kind of crater obtained.

33. Electrodes are usually made by mixing pure carbon or graphite with lampblack or some other binder, and after thoroughly mixing them, forcing a certain portion of the mixture through a die. The dies are quite ingenious. They are so arranged as to permit the extrusion of cylinders with hollow centres. These cylinders are then placed in cast-iron boxes, which are packed with powdered graphite and then heated in order to distill off the fluid components of the binder. The heating is preferably done in electric furnaces, so that the heat may be under control at all times and a uniform product produced. After baking or firing, the electrodes are " cored." This is done by squirting the core material into the shell. Next, the electrodes are tested, assorted and packed for shipment in moisture-proof containers.

TRAINING CONTROLS.

34. The movement of searchlights in aizmuth and elevation requires some form of training control. Some searchlights are operated by personnel adjacent to them. Other searchlights require training from remote points. It is with the training from remote points that most of the difficulty is experienced. For this service two classes of training control have been devised. They are known respectively as mechanical distant-training controls and electrical distant-training controls.

35. Mechanical distant-training controls are exemplified by pipe controls and cable controls. In the pipe control, a piece of gas pipe is attached to the trunnion of the searchlight, forming an elongation thereof. At the other end of the gas pipe is placed a tee, through which two handles are threaded. The whole forms a means by which an operator may rotate the searchlight in azimuth by walking around with it and may move the searchlight in elevation by twisting on the training control pipe. The scheme was developed by the British Expeditionary Forces in France and was used almost exclusively by them in the 1914–1918 operations in France. It is simple and easily operated. It permits the

searchlight pointer to quickly place the searchlight in any desired direction and at the same time to slowly train it in following a plane which has been picked up. It is limited, however, by the fact that the operator must of necessity be close to the searchlight, since pipe-training controls of this design cannot be more than about 12 or 15 feet long. It is illustrated in Fig. 31.

36. Cable training controls have been tried but have not been entirely successful. They have followed in general the designs used for many years on railway semaphore signalling. They

Fig. 31.

Sixty-inch, 150 ampere, high intensity arc, barrel type of searchlight and three meter paraboloid in an emplacement on the Meuse Front, showing pipe control for training searchlight.

have the very grave objection that they are not readily installed in temporary positions and that there is a great deal of back-lash giving inaccurate control. They have not been used to any great extent.

37. Electrical distant-training controls in wide variety have been used with searchlights for a number of years. Some of them have been successful. None of them, however, are suitable for field service, such as permitted the successful application of the British pipe control.

38. Electrical distant-training control systems may be divided in accordance with the system used for moving the searchlight. These may use series dc motors, shunt dc motors, synchronous ac

motors, asynchronous ac motors or solenoids. In addition, there may be combined with any one or more of these some form of hydraulic speed gear. All of these schemes use some form of relay for controlling the main training motor, and it is on account of this intermediary that many of them have been unsuccessful.

39. The requirements for a distant electrical training control are relatively severe. The control must be simple in construction,

FIG. 32.
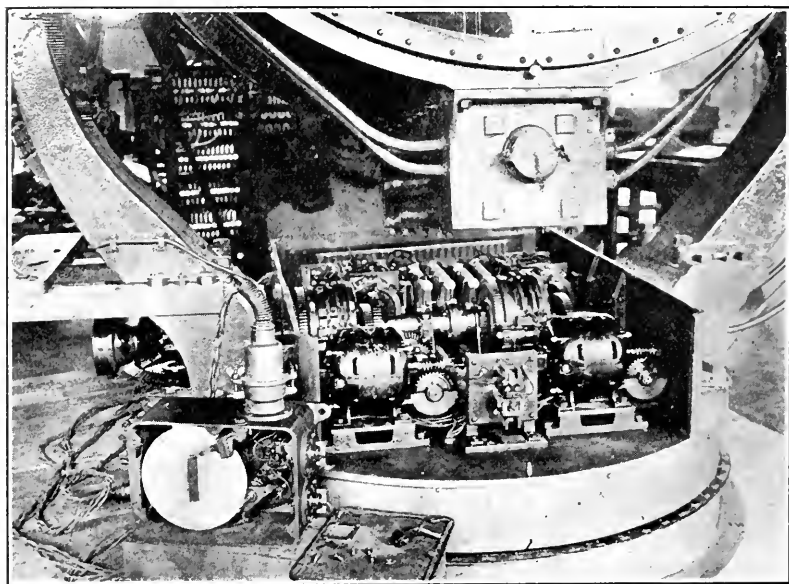
Mechanism details of distant electrical control for 60-inch barrel type of searchlight.

require a minimum number of electric wires, be light in weight and preferably be so arranged that a position indicater may be added without too great complication. The training requires a torque of from 75 to 300 foot-pounds, depending upon the size and weight of the searchlight. The control must be so arranged that the searchlight may be revolved at a maximum speed of four to five rpm. or at a minimum speed of $1/100$ of an rpm. in both azimuth and elevation. The control mechanism must also be of such nature that the searchlight may be operated from a distance of 200 yards, as well as from a distance of 10,000 yards. The operation of the field equipment is usually at points from 200 to

FIG. 33.
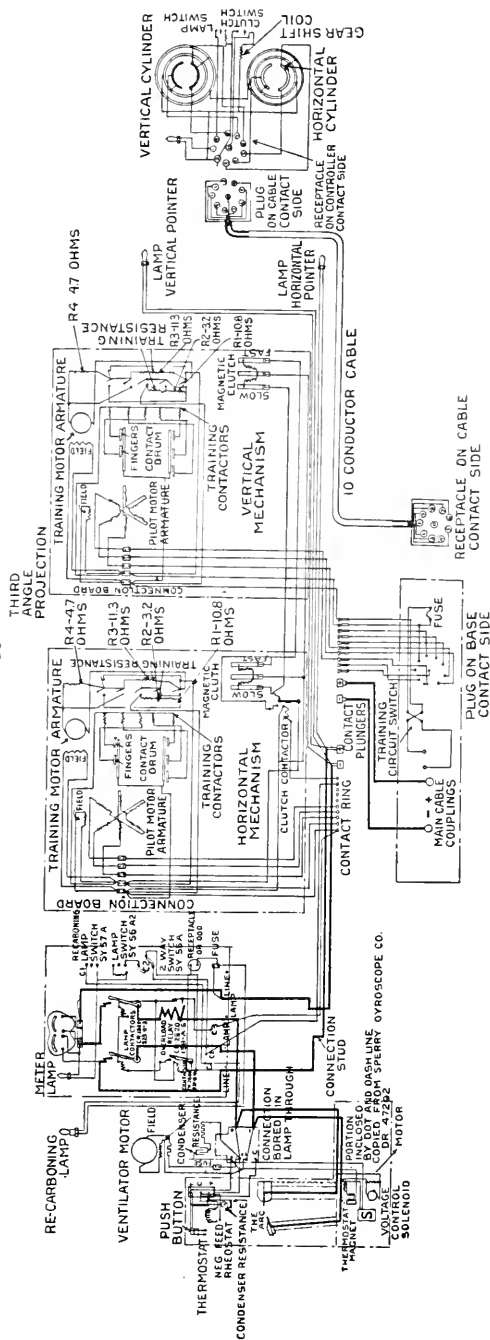
Wiring details of distant electrical control for 60-inch barrel type of searchlight.

300 yards from the searchlights, while the operation of coast-defense searchlights is from positions ranging from 1000 to 6000 yards or more distant.

40. Direct-current motors have, up to date, furnished the best form of distant electrical training control. A recent and very successful development along these lines for the heavy coast-defense searchlights is shown in Fig. 32. The diagram of connections for this is shown in Fig. 33. It is very well adapted for coast-defense conditions where the searchlights and control stations are built into fixed positions. It is too heavy, however, for application to field searchlights.

41. A number of different kinds of direct-current and alternating-current schemes have been tried for the distant electrical control of field searchlights. For this service extreme simplicity, ruggedness, dependability and light weight are essential. None of the schemes which have been tried have been found successful for this service, although several promising ones are now in development.

INDICATORS.

42. Devices for accurately indicating at a distant point the position of a searchlight in azimuth and elevation are among the things still desired. A suitable indicator must be accurate to within one-fourth of a degree. It must be relatively light in weight and simple in operation. It must be self-synchronizing and easily readable.

43. Several forms of direct-current indicators have been developed and tried. The step-by-step indicator requires too many points and too great a complication to give accuracy. The iron armature indicator with a trifurcated direct-current field has no means of overcoming its inherent energy loss and, therefore, permits an error to creep into the indications. The alternating-current schemes, using induction motors or synchronous motors, seem promising. However, they are relatively heavy and require a different kind of current than is ordinarily available at searchlight positions. The result is that there has not been yet developed a suitable indicator for general service with searchlights. However, it should be noted that there are a number of investigators working on this problem at the present time. Partial solutions have been obtained, and it is believed that before long a suitable indicator will be available.

(To be concluded.)

POISONOUS GASES FROM CARBON TETRACHLORIDE FIRE EXTINGUISHERS.*

BY

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INTRODUCTION.

During the construction of a submarine boat at the Navy Yard, Portsmouth, N. H., in August, 1919, an incipient fire .occurred in one of the compartments, which was small and closely confined. A carbon tetrachloride fire extinguisher put out the blaze, but the men who used it were overcome by the fumes which they inhaled, and several days later died. They had the usual symptoms of poisoning due to a pulmonary, irritant gas.

At the request of the Bureau of Construction and Repair of the Navy Department, the Bureau of Mines investigated the effect of heat on carbon tetrachloride extinguishers with special reference to the nature of the decomposition products. The Pittsburgh Experiment Station has particularly good facilities for conducting gas investigations, and was also interested in the same subject in view of the use of carbon tetrachloride extinguishers in small rooms in mines for combating mine fires.

An employee of the Bureau of Mines suffered a similar though not fatal experience. While he was driving an automobile truck, a fire burst out under the engine hood. The auto was stopped but the engine continued to run. The driver stood on the running-board about three feet from the fire and applied carbon tetrachloride liquid from an extinguisher. The fire was put out but the engine fan blew the fumes which were generated back into the man's face. Inhalation of the gases caused him to lose consciousness and he fell to the ground. Several minutes elapsed before he was revived. A soreness of the respiratory system remained for weeks, then passed away, and no serious consequences resulted. This incident, and others not cited, show that there is a real danger in breathing these fumes under certain conditions at least.

A gastight chamber of 1000 cubic feet capacity was used for the first experiments with the carbon tetrachloride fire-extin-

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* Communicated by the Director of the Bureau of Mines.

543

guisher liquids. Confirming experiments were made with carbon tetrachloride liquids, vaporized in air and passed through an electric-tube furnace of regulated temperature. The latter experiments substantiated the results obtained with actual fire in the chamber.

Phosgene, one of the most poisonous gases used in warfare, was found; also chlorine, another very poisonous gas; hydrogen chloride, which is less poisonous but is irritating to the mucous membrane; and the vapor of carbon tetrachloride itself, which is a dangerous anæsthetic. As a result of the experiments, it is recommended that carbon tetrachloride extinguishers be not used on fires in confined spaces by persons who are not protected from the gases arising, or who are unable to hold their breath and get away from the immediate vicinity of the fire at once after applying the extinguisher. The army type of gas mask affords good protection from the products of carbon tetrachloride decomposed by fires and its use is recommended for the purpose.

It is not the intention of this paper to discourage the use of carbon tetrachloride fire extinguishers, which are very effective for stopping incipient fires, because in most cases, ventilation or the large amount of air usually present, prevents the formation of dangerous concentrations of gas. Also, the operator can nearly always escape easily and quickly from the vicinity of the gas when he knows he should do so. Rather the purpose is to show the danger of using such extinguishers in small, unventilated places where escape is impossible.

PREVIOUS INVESTIGATIONS.

In 1868 Schutzenberger [1] found that phosgene was produced from carbon tetrachloride by passing the vapor, mixed with carbon dioxide, over pumice heated to 350–400° Centigrade. The probable reaction is

$$CCl_4 + CO_2 = 2COCl_2 \qquad (1)$$

Later he found that at temperature of a water bath phosgene was formed from carbon tetrachloride with oxygen supplied by sulfur trioxide [2] according to the equation

$$CCl_4 + 2SO_3 = COCl_2 + S_2O_5Cl_2 \qquad (2)$$

[1] Schutzenberger. P., Sus quelques reactions donnant lieu à la formation de l'oxychlorure de carbone; *Compt. Rend.*, vol. lxvi, 1868, pp. 747–8.

[2] Schutzenberger, P., Über die Einwirkung des Schwefelsaure-Anhydrids auf Kohlenstoffsuperchloride; *Ann. der Chem.*, vol. cliv, 1870, pp. 375–6.

Goldschmidt [3] found that carbon tetrachloride heated to $250°$ Centigrade in a sealed tube with a large amount of water, yielded carbon dioxide and hydrogen chloride. The equation probably is

$$CCl_4 + 2H_2O = CO_2 + 4HCl \qquad (3)$$

With a small amount of water, phosgene was formed. The equation for this is probably

$$CCl_4 + H_2O = COCl_2 + 2HCl \qquad (4)$$

Many other oxides react with carbon tetrachloride when heated with production of phosgene as found by Camboulives.[4] Silicon dioxide is an exception. Iron oxide reacted at $245°$ Centigrade. The reaction is probably

$$3CCl_4 + Fe_2O_3 = 3COCl_2 + 2FeCl_3 \qquad (5)$$
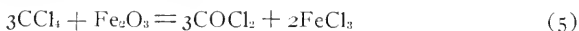
Carbon tetrachloride passed through a glowing tube decomposes, according to Beilstein,[5] as expressed by the equations

$$2 CCl_4 + heat = C_2Cl_4 + 2Cl_2 \qquad (6)$$
$$2 CCl_4 + heat = C_2Cl_6 + Cl_2 \qquad (7)$$
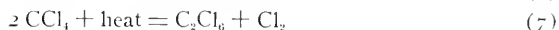
That there is danger from gases arising from carbon tetrachloride fire-extinguisher liquids has been recognized by the trade. In a folder descriptive of hand fire extinguishers, the Fire Extinguisher Exchange, Cleveland, Ohio, states: " Carbon tetrachloride, the base of the liquid used in the one-quart extinguishers, strongly resembles chloroform in its physiological action; it is not now used as an anæsthetic as several deaths are laid to its charge. Under heat it gives off chlorine gas. Its use is dangerous in confined spaces."

CHEMICAL EXAMINATION OF THE FIRE-EXTINGUISHER LIQUIDS.

Commercial carbon tetrachloride and three extinguisher liquids produced by manufacturers were used in the experiments. Qualitative tests for carbon bisulfide and chloroform gave the following results:

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[3] Goldschmidt, H., Über die Einwirkung von molecularem Silber auf die Kohlenstoffchloride; *Ber. Deut. Chem. Gesell.*, vol. xiv, 1881, pp. 927–30.

[4] Camboulives, P., Action des vapeurs de tetrachlorure de carbone sur les anhydrides et les oxydes; *Compt. Rend.*, vol. cl. 1910, pp. 175–7.

[5] Beilstein, F., Handbuch der organischen chemie; vol. i, third edition, 1893, p. 146.

Kind of Liquid	Presence of Carbon Bisulfide	Presence of Chloroform
Commercial Carbon Tetrachloride	Present	Absent
Extinguisher Liquid No. 1	Present	Present
Extinguisher Liquid No. 2	Present	Present
Extinguisher Liquid No. 3	Present	Present

Analytical distillation of the liquids gave the results in Table I, determined by Dr. E. W. Dean, of the Bureau of Mines Petroleum Laboratory.

TABLE I.

Results of Distillation of Carbon Tetrachloride Fire Extinguisher Liquids. 200 c.c. Distilled in a 6-inch Hempel Flask.

Amount distilled, per cent.	Commercial carbon tetrachloride. Barometer 739 mm.		Liquid No. 1 Barometer 730 mm.		Liquid No. 2 Barometer 743 mm.		Liquid No. 3 Barometer 738 mm.	
	Temp. ° C.	Sp. Gr.	Temp. ° C.	Sp. Gr. at 15 ° C.	Temp. ° C.	Sp. Gr. at 15° C.	Temp. ° C.	Sp. Gr. at 15° C.
First drop	67.0	. . . . .	54	. . . . .	54	. . . . .	60	. . . .
1	71.0	. . . . .	68	. . . . .	69	. . . . .	62	. . . . .
2	72.0	. . . . .	69	. . . . .	70	. . . . .	71	. . . . .
10	74.3	1.599	71	1.567	71.5	1.564	71	1.570
20	74.8	1.596	71.5	1.579	72	1.580	71.5	1.584
30	75.0	1.600	72	1.583	73	1.585	72.0	1.584
40	75.1	1.600	72.5	1.588	73	1.588	72.5	1.587
50	75.3	1.603	73	1.591	73.5	1.593	73.0	1.588
60	75.3	1.603	73	1.591	74	1.595	73.5	1.590
70	75.4	1.603	73.7	1.596	74.5	1.598	74.0	1.597
80	75.5	1.604	74	1.598	75	1.601	74.5	1.597
90	75.5	1.606	74.3	1.601	75.5	1.602	75.5	1.599
95	75.5	1.606	74.5	1.603	76	1.603	75.5	1.601
Dry point	75.5	. . . . .	74.5	. . . . .	76	. . . . .	. . . . .	. . . . .
Distilled...	97.1 percent.	. . . . .	97.5 percent.	. . . . .	95 percent.	. . . . .	. . . . .	95 percent.
Residue...	1.3 percent.	. . . . .	1.6 percent.	. . . . .	4.5 percent.	.897	. . . . .	2.5 percent.
REMARKS..	First distillate gave odor of carbon bisulfide.		First distillate smelled of chloroform.		First distillate smelled of carbon bisulfide. Residue smelled of kerosene and was inflammable.		First distillate smelled of chloroform. Residue smelled of turpentine, but consisted of a tarry mass which decomposed by the heating.	

From the results of Table I, it appears that the first of the commercial extinguisher liquids was carbon tetrachloride with an admixture of chloroform to prevent freezing. Number 2 was

a mixture of carbon tetrachloride and a high-boiling petroleum distillate, added for the same purpose. Number 3 was a mixture of carbon tetrachloride with chloroform and turpentine. The purpose of the turpentine was to prevent escape of poisonous gases, such as chlorine, from the liquids when heated, but, as will

FIG. 1.

Legend
a = Std. W.I. pipe threaded both ends set with two nuts and rubber gaskets
b = 8" Flange in roof for exhaust flue
c = 12" Flange in roof for exhaust flue
d = Motor
e = Fan
f = Refrigerator doors
g = 25 Pound weight to submerge bell sides in mercury well
h = Annular mercury well
i = Round throated ferrule - ¼" hole
j = ⅜" galv. metal sash cord

Right side elevation

Plan

No 24 gage steel roof
No 16 gage steel floor
All sheet metal joints soldered
Back center panel has glass
at top and bottom

Ceiling

To hood

Roof of gas house

Detail of flue valves

Details of gas chamber used at the Pittsburgh Experiment Station of the Bureau of Mines for experimental purposes.

be shown later, it failed to do so. The carbon bisulfide found existed as impurity in the original carbon tetrachloride used to make the liquids.

EXPERIMENTS WITH FIRES IN THE CLOSED ROOM.

Apparatus and Procedure.—In Fig. 1, there are shown the details of the room or gas chamber used at the Pittsburgh Experiment Station of the Bureau of Mines for experimental pur-

poses. Plate I is a photograph of the chamber. The floor, walls
and ceiling are constructed entirely of sheet metal. The windows
are of glass, and the doors of wood, such as are made for large
refrigerators. They are lined on the inside with sheet metal.
Their edges are bordered with rubber; handles, made to exert a
clamping effect, fasten the doors tightly against their jams.

PLATE I.
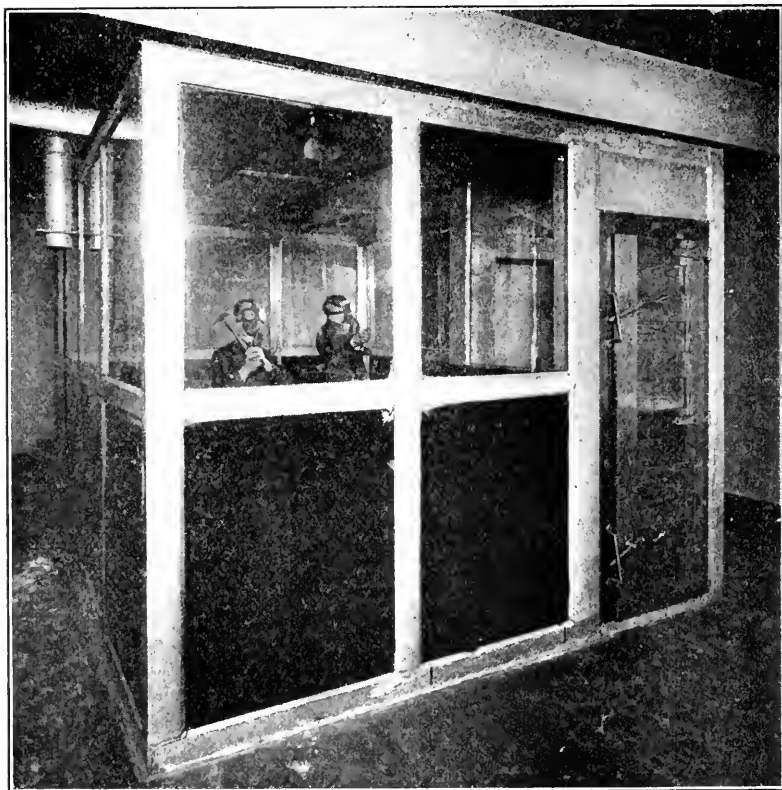
Gas chamber used at the Pittsburgh Experiment Station of the Bureau of Mines for experi-
mental purposes.

All metal joints are soldered. The glass windows are cemented
in the metal sash with a putty containing linseed oil and red lead,
so the glass to metal joints are airtight. Special valves are set
in the roof for connecting the room with a flue leading to an
exhaust fan. The valve consists of a sheet-iron bell suspended

in a tube of slightly larger diameter. At the bottom of the tube, inside, is an annular space containing mercury. When the bell is seated in the annular space, the mercury seal makes the valve gas-tight. A chain attached to the bell runs over pulleys to a point where it may be reached by one on the outside of the chamber. Raising the bell into a closed space above a T in the pipe causes the gases in the chamber to be sucked out.

Experiments have shown that the room is nearly gas-tight. Interchange of gas between the inside and outside of the closed chamber amounts to less than 10 per cent. of the chamber volume per 24 hours.

To determine the behavior of both commercial carbon tetrachloride and the extinguisher liquids as regards breaking up and the nature of the gases given off when the liquid is put on a fire, experiments were made with small fires of excelsior and other inflammable material in the 1000 cu.-ft. chamber. Other experiments were made in the same chamber, in which the extinguisher liquids were poured upon red-hot iron, as it was thought that in the Portsmouth accident, liquid was possibly squirted upon an electric arc or hot metal that was being welded. A six-inch channel iron was heated to bright cherry red over a length of two feet. It was then quickly placed near the floor of the chamber, and the contents of a quart fire extinguisher steadily sprayed or poured upon it. The operator of the fire extinguisher wore a gas mask or one-half-hour breathing apparatus. After emptying the extinguisher on the iron or extinguishing the fire, the fan was started and samples of gas were taken for analysis as soon as the concentration became uniform.

Results of Experiments.—The results of the experiments are given in Table II.

Reference to the table shows that in all experiments the atmosphere created by using the fire extinguisher was dangerous. A rather surprising result of this investigation was the fact that the poisonous gas, phosgene, was liberated in every experiment, and in all cases in toxic quantities.

Experiment No. 1, in which 500 c.c. of carbon tetrachloride was poured on a red-hot, four-inch " I " beam, showed 168 parts per million of phosgene in the chamber atmosphere of 1000 cubic feet. This is a fatal concentration. Twenty-five parts per million will kill a man after breathing for half an hour; five parts per

TABLE II.

Results of Experiments with Heated Carbon Tetrachloride Fire Extinguisher Liquids in the Closed Chamber.

Experiment No.	Liquid used	Volume of liquid used c.c.	Source of heat	Estimated temp. °C.	CCl_4 P.P.M.	HCl P.P.M.	$COCl_2$ P.P.M.	Cl_2 P.P.M.	CO per cent.	CO_2 per cent.	O_2 per cent.	N_2 per cent.	Color of smoke
1	Com'l. CCl_4	800	4 inch "I" beam	825	4350	144	168	0	.00	.03	20.51	79.46	Yellow like chlorine (1)
2	Ditto	1000	6 in. channel	600	5850	...	80	23	.00	.4	20.3	79.3	Ditto (2)
3	Ditto	1000	Excelsior fire	...	5130	110	60	0	.41	3.49	16.59	79.39 CH_4.12	Red-brown, nearly black
4	No. 1	1000	Ditto	...	4970	82	15	0	.17	1.22	19.70	78.68 CH_4.17	Ditto (3)
5	No. 2	300	Ditto	...	2000	65	19	0	.22	.81	19.87	79.06 H_2.04	Ditto (4)
6	No. 1	400	6 inch channel	825	2607	60	30	10	.16	.31	20.68	78.84 H_2.01	Yellow like chlorine (5)
7	No. 2	1000	6 inch channel plus 4" "I" beam	950	2078	236	42	0	.22	.36	20.52	78.90	Black (6)

REMARKS:
(1) Odor of CCl_4 and HCl was noticed.
(2) Phosgene could be detected by odor.
(3) Could detect HCl and $COCl_2$ by odor.
(4) Could detect HCl and $COCl_2$ by odor.
(5) Could detect HCl and $COCl_2$ by odor.
(6) Liquid burned on iron with a flickering flame.

million produce coughing and irritation, and are dangerous after a time.

Chlorine was not found as a decomposition product in most of the experiments. Experiments Nos. 2 and 6 show some chlorine—not enough to be considered very dangerous, since in equal concentrations, it is somewhat less poisonous than the phosgene. However, 23 parts per million are exceedingly irritating and breathing it would produce bad effects. It is possible that some chlorine was absorbed by the asphalt paint on the chamber.

Small quantities of carbon monoxide were given off in most of the experiments, both with fires and with heated iron. The larger quantity was found with the excelsior fire. That evolved from the liquids on iron would produce headache and nausea by itself in a short time. The hydrochloric acid gas was present in quantity sufficient to be very irritating. Carbon tetrachloride vaporized to concentrations ranging from .2 to .6 per cent., or 2000 to 6000 parts per million. This concentration is not considered enough to produce anæsthesia in a short time. However, if the chamber volume were much smaller, there would undoubtedly be concentration of carbon tetrachloride vapor itself high enough to produce anæsthesia, and men would very quickly become unconscious. After this, the phosgene present would produce effects in the lungs and respiratory system that would surely prove fatal.

When commercial carbon tetrachloride is poured upon red-hot iron, it produces a yellowish smoke that looks much as though chlorine were one of the decomposition products. However, this is not the cause, and no chlorine was found—either by chemical test or odor—except in Experiments 2 and 6.

The predominating odor was carbon tetrachloride itself, phosgene, and hydrochloric acid. The yellowish color was found to be due to iron chloride formed by interaction between the hot iron and carbon tetrachloride. The iron chloride is vaporized, then reacts with the moisture in the air, hydrolizes, and forms hydrochloric acid and iron oxide. Liquid No. 1 gives the same sort of smoke as commercial carbon tetrachloride, while Liquid No. 2 gives a black smoke, due apparently to particles of carbon formed by decomposition of the kerosene or other petroleum oil that is put in this extinguisher to lower the freezing point.

It was, of course, impossible for a man to take even one

breath of the atmosphere created in the gas chamber, while spray-
ing the extinguisher on hot iron or burning excelsior.

EXPERIMENTS WITH HEATED TUBES.

The experiments in the closed room gave results which simu-
late the action of carbon tetrachloride liquids in actual use. But
the nature of the reaction which occurs could not be studied
readily in such experiments because of the impossibility of con-
trolling some of the factors, such as temperature and humidity,
which undoubtedly influence the decomposition. For that reason,

Fig. 2.
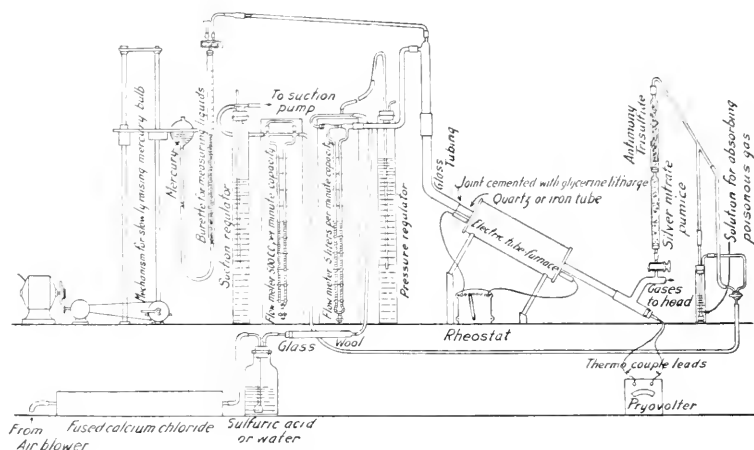
Apparatus for studying decomposition of carbon tetrachloride liquids in heated tubes.

other experiments were arranged with apparatus in which the
conditions could be accurately controlled.

Apparatus and Procedure.—Figure 2 shows the apparatus
diagrammatically. Air was passed at a uniform rate of 5 litres
per minute through an electrically-heated tube furnace. The
liquids being tested were added to the air stream in fluid form,
at a uniform, measured rate, by means of a mechanism which
continuously raised a mercury leveling bulb connected to a burette.
As the mercury entered the burette, it displaced carbon tetrachlo-
ride liquid which ran into the tube carrying the air current.
The liquid all evaporated into the air stream before the hot parts
of the furnace were reached. Temperature at the centre of the
furnace was measured by means of a platinum, platinum-rhodium

thermocouple and pyrovolter. The temperature through the furnace was of course not uniform, because the air absorbed some heat at the entrance. The temperature at the centre may be considered an average.

Samples were taken of the mixtures of gases which passed out of the heated tube. The volume of the samples of gas used for analysis was determined by means of a flowmeter of 500 c.c. per minute capacity. Various absorbents for the different gaseous constituents to be determined were placed between the main gas stream and the sample flowmeter.

Experiments were made at 600° and 800° Centigrade, with humid and dry air and with heated tubes of iron and of quartz.

The first experiments were made with chemically-pure carbon tetrachloride to secure comparative results under the different conditions of experiments, as regards temperature, humidity, and tube material. After these experiments, the different extinguisher liquids in question were studied for decomposition, using wet air, a quartz tube and a temperature of 800° Centigrade, which seemed best for the purpose,

Results of Experiments with Chemically-pure Carbon Tetrachloride.—The results of the experiments with pure carbon tetrachloride are summarized in Table III. Taking up the columns in order: Column 1 gives the number of determinations of each of the different gas constituents, of which the averages are reported in succeeding columns; results of at least three determinations are included. As stated under " Remarks," the differences were small, about two or three per cent. Column 3 gives the temperature of the heated tube; 600° and 800° Centigrade were used. Variations up to 15° from these temperatures occurred. Column 4 states the material of the heated tube. Iron was first used to obtain results comparable with those of the experiments with the channel irons in the gas chamber. Iron oxide on the surface was found to influence the reaction and a quartz tube was used later.

Columns 5 and 6 state respectively the amounts of carbon tetrachloride in the air passing through the hot tube, by weight, and by volume of the vapor as a perfect gas, at room temperature. Differences in concentrations varied over a range of about 8 per cent. Since the final figures are expressed in terms of percentage of these concentrations, the small differences should not influence the conclusions drawn.

TABLE III.

Results of Tests of Chemically Pure Carbon Tetrachloride. Rate of Flow of Air—Five Liters per Minute.

Number of tests averaged	Air condition	Temp. °C.	Material of heated tube	Carbon tetrachloride (CCl4) vapor in air		Decomposition products [a]								Undecomposed carbon tetrachloride (CCl4) Calculated [c]		Chlorine in decomposition products compared to chlorine in original carbon tetrachloride (CCl4) [d] Per cent.			
						Phosgene (COCl2)		Chlorine (Cl2)		Total chlorides [b] as hydrogen chloride (HCl).		Hydrogen chloride (HCl). Calculated				Phosgene COCl2	Chlorine (Cl2)	Hydrogen chloride (HCl)	Undecomposed carbon tetrachloride (CCl4)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
				mg.p.l.	p.p.m.	mg.p.l.	p.p.m.	mg.p.l.	p.p.m.	mg.p.l.	p.p.m.	mg.p.l.	p.p.m.	mg.p.l.	p.p.m.				
1	Wet	600	Iron	92.6	14700	15.0	3700	5.0	1700	46.5	31000	30.2	20260	43.6	6920	12.6	5.9	34.4	47.1
3	Dry	600	Iron	91.8	14580	9.7	2400	28.0	9000	34.5	23000	−1.5[c]	....	55.5	8810	8.3	33.1	−1.8[e]	60.4
4	Wet	600	Quartz	86.0	13050	2.4	600	.7	210	3.6	2400	1.1	740	82.1	13000	2.2	.9	1.4	95.0
3	Dry	600	Quartz	90.2	14320	.0	0	1.1	400	2.0	1320	.8[e]	....	88.1	14000	.0	1.3	.96[e]	97.7
3	Wet	800	Quartz	84.8	13470	14.4	3550	16.2	5600	34.5	23000	7.2	4830	48.5	7700	13.2	20.7	8.9	57.2
3	Dry	800	Quartz	89.2	14170	12.8	3150	14.4	4970	24.4	16300	.1[e]	....	63.5	10000	11.2	17.5	.1[e]	71.2

REMARKS:

[a] Differences in triplicate analytical determinations of gases in the various experiments ranged up to a maximum of about 10 per cent. of their values.

[b] Chlorine is included in total chlorides, as it is absorbed and reduced to chlorides by the alcoholic sodium hydroxide solution used. Carbon tetrachloride did not react; ferric chloride was caught in cold tubes before reaching the absorbent. These are not included in total chlorides as determined.

[c] Possible compounds such as C_2Cl_4, C_2Cl_6, $CHCl_3$ and also $FeCl_3$ are calculated here as CCl_4 on a chlorine content basis.

[d] Since the phosgene generated can contain a maximum of only 50 per cent. of the carbon tetrachloride, the percentage of carbon tetrachloride represented by the phosgene is twice that stated for chlorine content comparison. For the other gases, the percentages given for chlorine may be considered to represent also the percentage of the carbon tetrachloride decomposed to form the products.

Figures representing hydrogen chloride, less than one milligram per liter, or one per cent., have no value, because experimental errors exceed this. They are included only for use in comparisons.

Columns 7 to 16, inclusive, give the results of determinations of phosgene, chlorine, hydrogen chloride, total chlorides (as hydrogen chloride), and undecomposed carbon tetrachloride; each in terms of weight and gas volumes. The phosgene, chlorine and total chlorides were determined directly by analysis. Total chlorides includes the phosgene, hydrogen chloride and the chlorine, which was caught and reduced to chlorides by the alcoholic sodium hydroxide solution used, but does not include carbon tetrachloride, which did not react in the analysis; or any ferric chloride, which was precipitated from the gases by the cold tubes and glass wool put into them before the gases reached the absorbing solution.

Hydrogen chloride was calculated by subtracting from the weight of chlorine in the total chlorides the sum of the weight of chlorine in the phosgene and free chlorine, and converting the difference into hydrogen chloride. Undecomposed carbon tetrachloride was calculated by subtracting from the weight of chlorine in the original carbon tetrachloride the weight of chlorine in the total chlorides, and converting the difference into carbon tetrachloride. The figures for undecomposed carbon tetrachloride thus include any tetrachlorethylene (C_2Cl_4), hexachlorethane (C_2Cl_6), ferric chloride ($FeCl_3$), or chloroform ($CHCl_3$), computed on the basis of their chlorine content.

Columns 17 to 20, inclusive, give the percentages by weight of the chlorine apportioned among the products, phosgene, free chlorine, hydrogen chloride and undecomposed carbon tetrachloride. The figures for hydrogen chloride which are less than one per cent. have no value, because the experimental errors exceed them. They are included in the table only for use in making comparisons.

Phosgene generated from the carbon tetrachloride can contain a maximum of but 50 per cent. of the chlorine in the carbon tetrachloride. Hence, the molecular percentage of carbon tetrachloride which was converted into phosgene is twice that stated as a result of comparing their chlorine contents. For the other gases, the percentages given by comparing the chlorine in them with the chlorine in the original carbon tetrachloride, may be considered to represent the percentage of carbon tetrachloride decomposed to form them.

Discussion of the Results.—Table III shows that at 600°

TABLE IV.

Results of Tests with Commercial Fire Extinguisher Liquids and Heated Tube. Rate of Flow of Air—Five Liters per Minute; Air Condition—Saturated with Water Vapor at Room Temperature; Material of Tube—Quartz; Temperature at Middle of Tube—800° ±10° Centigrade.

Fire extinguisher liquid	Number of tests averaged	Carbon tetrachloride (CCl₄) vapor in air		Decomposition products										Chlorine in decomposition products compared to chlorine in original carbon tetrachloride (CCl₄) Per cent.			
				Phosgene (COCl₂)		Chlorine (Cl₂)		Total chlorides as hydrogen chloride (HCl)		Hydrogen chloride (HCl) calculated		Undecomposed carbon tetrachloride (CCl₄) calculated		Phosgene (COCl₂)	Chlorine (Cl₂)	Hydrogen chloride (HCl)	Undecomposed carbon tetrachloride (CCl₄)
		mg.p.l.	p.p.m.	mg.p.l.	p.p.m.	mg.p.l.	p.p.m.	mg.p.l.	p.p.m.	mg.p.l.	p.p.m.	mg.p.l.	p.p.m.				
Commercial carbon tetrachloride	3	91.4	14500	16.2	4000	15.8	5400	34.6	23200	6.4	4290	55.0	8730	13.8	18.7	7.4	60.1
No. 1	3	87.0	13800	15.0	3700	16.0	5500	32.2	21600	4.6	3090	53.1	8430	13.5	19.9	5.6	61.0*
No. 2	3	90.4	14350	14.4	3800	13.0	4400	32.8	22000	8.8	5900	55.8	8860	12.3	15.6	10.3	61.8†
No. 3	3	91.2	14480	15.0	3700	10.2	3500	31.9	21400	10.3	6910	59.6	9460	12.9	12.1	11.9	63.1‡

* Liquid contained chloroform.
† Liquid contained chloroform and keronene, or other heavy petroleum distillate.
‡ Liquid contained chloroform and turpentine.

Centigrade, carbon tetrachloride vapor in air decomposes much more readily in contact with iron or oxide of iron than in contact with a solid substance chemically inert to it, as quartz. Phosgene is generated in greater quantity when the atmosphere is moist than when dry; in fact, no phosgene was formed in dry air at 600° in contact with quartz, but in contact with oxide-covered iron, 8.3 per cent. of the chlorine in carbon tetrachloride changed to combination in phosgene.

More free chlorine was formed with dry air in the iron tube at 600° than in the quartz tube, and much more was formed in the iron tube with dry air than with wet.

On the whole, the presence of hot reactive substances, as either water vapor or oxide of iron, or possibly metallic iron, seems to promote the decomposition of carbon tetrachloride vapor, and the effect of the iron oxide is greater than that of the water vapor.

In the experiments with the quartz tube at 800° Centigrade, more of each of the decomposition products was formed than in the quartz at 600°, whether moisture was present or absent; and the greater production of each product occurred with the moisture present.

Equations (1) to (5) which have already been stated can account for most of the phenomena observed. In addition to these, the experiments with carbon tetrachloride vapor in dry air heated to 800° Centigrade gives rise to phosgene. This undoubtedly occurs according to this equation:

$$2CCl_4 + O_2 = 2\,COCl_2 + 2Cl_2 \qquad (6)$$
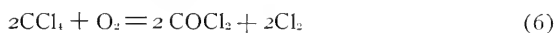
Of the conditions used in these experiments with the chemically-pure carbon tetrachloride, the quartz tube at 800° Centigrade and humid air, seemed to be most suitable for the study of the commercial liquids, so they were applied in the experiments following.

Results of Experiments with Commercial Fire-extinguisher Liquids.—Table IV gives the results of the experiments with the commercial liquids in the heated tube. Since the figures and the methods of obtaining them are like those reported for Table III, they need no special explanation. The figures show that at 800°, in presence of water vapor, commercial fire-extinguisher liquids may be decomposed to a large extent with formation of poisonous products. Phosgene was produced in nearly equal quantities

from all the liquids; 12.3 to 13.8 per cent. of the original chlorine was found in final combination as phosgene. Chlorine was produced as a result of decomposition of about 12 to 20 per cent. of the original carbon tetrachloride. The low figure, 12 per cent., was obtained with the liquid which had turpentine added to it. Turpentine, which is very active toward chlorine, thus seems to inhibit the formation of free chlorine, but it has little, if any, inhibiting effect on phosgene. Hydrogen chloride figures ranged from 5.6 to 11.9 per cent. As might be expected, the greatest amount was obtained with the liquid containing turpentine. About 60 to 63 per cent. of the liquids passed through the heat without decomposition.

Altogether the results of the experiments with the heated tubes entirely substantiate the results obtained with the actual fires and hot metal in the gas chamber, and confirm the conclusions that gases arising from the use of carbon tetrachloride liquids for extinguishing even small fires are poisonous and formed in sufficient quantity to poison the air of small unventilated spaces. Such extinguishers should not be used by persons unprotected from the fumes, who are unable to hold their breath long enough to escape from the dangerous atmosphere.

TOXICITY OF THE GASES.

Data on the toxicity to man and animals of carbon tetrachloride, chlorine, chloroform, hydrogen chloride and phosgene have been collected from reports made by various investigators and arranged for comparison in Table V.

Standards of measurement used by different investigators have not been uniform, so the different results are difficult to put into a homogeneous table. Some liberties have been taken in transposing and arranging some of the data. For this reason, reference to original sources, which are cited in all cases, should be made when exact statements are wanted. The table shows that the order of toxicity is this: (1) Phosgene, (2) chlorine, (3) hydrogen chloride, (4) carbon tetrachloride, and (5) chloroform.

METHODS OF ANALYSIS OF THE GASES.

The methods used and the necessary reagents and apparatus for determining chlorine, phosgene, hydrogen chloride and carbon tetrachloride in the air containing the decomposition products

are described very briefly below. Underlying principles were the same in analyzing the dilute gases from the chamber and the more concentrated ones from the heated tube. The volume of sample from the chamber was usually 4 or 5 litres at room temperature, and was taken by water aspirating and measurement of the water displaced. About one-tenth to one-fifth of this volume was used with the heated tube; measurement being made with the flow meter and length of time of passing the sample. The rate of passing the gases through absorbents was one litre per minute or less. Constituents were determined in the order stated.

Chlorine.—The measured gas sample was passed directly through 50 c.c. of a 5 per cent. solution of potassium iodide, contained in a tube with bubbler of the petticoat type. Liberated iodine was titrated with 3/100 normal sodium thiosulfate solution and starch indicator.

Phosgene.—The gas was passed through a train of reagents in this order:

(*a*) Silver nitrate on granular pumice contained in a tube as detailed in Fig. 4. This was for removing hydrogen chloride.

(*b*) Powdered antimony trisulfide, interspersed through glass wool contained in a similar tube, to remove chlorine.

(*c*) Fifty cubic centimetres of sodium hydroxide solution in 85 per cent. alcohol. This was for absorbing the phosgene, which hydrolyzed to produce sodium chloride. The chloride was determined by the Mohr method of titration with standard silver nitrate solution and potassium chromate indicator. A blank determination for chlorides in the caustic solution was subtracted from the results and phosgene then calculated.

A diagram of the apparatus used to take a sample of gas from the chamber for determining phosgene in the absence of chlorine is shown in Fig. 3.

The silver nitrate pumice was made by dissolving 100 grams of silver nitrate in 330 cubic centimetres of boiling water, adding to this approximately one litre of 8- to 14-mesh pumice, stirring thoroughly, cooling, draining excess fluid and drying in a water oven at 100° Centigrade.

Hydrogen Chloride.—Gas samples were aspirated directly through 50 cubic centimetres of the alcoholic caustic solution. All the chlorine in the form of free chlorine, phosgene and hydro-

TABLE V.

Toxicities of Air Containing Gases and Vapors from Fire Extinguishers.

	Carbon tetrachloride	Chlorine	Chloroform	Hydrogen chloride	Phosgene
Least detectable odor:					
Milligrams per liter	4.5^5	0.010^1	3.3^5	……	0.023^1
Parts per million	718^5	3.5^1	67.4^5	……	5.6^1
Irritation:					
Eyes:					
Milligrams per liter	……	……	……	……	$.016^1$
Parts per million	……	……	……	……	4^1
Throat:					
Milligrams per liter	……	0.44^1	……	……	$.0126^1$
Parts per million	……	15.1^1	……	……	3.1^1
Coughing:					
Milligrams per liter	……	$.088^1$	……	……	$.019^1$
Parts per million	……	30.2^1	……	……	4.8^1
Slight symptoms after several hours:					
Milligrams per liter	10^2	$.0029^2$	$1.^2$	$.015^2$	$.004^1$
Parts per million	1600^2	$1.^2$	200^2	10^2	$1.^1$
Maximum amount that can be inhaled for one hour without serious disturbances:					
Milligrams per liter	$25-40^2$	$.012^2$	$25-30^2$	$0.075-0.150^2$	……
Parts per million	$4000-6200^2$	$4.^2$	$5100-6200^2$	$50-100^2$	……
Dangerous in thirty minutes to one hour:					
Milligrams per liter	$150-200^2$	$0.12-0.17^2$	70^2	$2.2-3.0^2$	……
Parts per million	$24000-32000^2$	$40-60^2$	14000^2	$1500-2000^2$	……
Noxiousness, impossible to breathe several minutes:					
Milligrams per liter	……	0.015^3	……	$0.1-0.3^1$	$.02^3$
Parts per million	……	5^3	……	$66-200^1$	5^3

Toxicity of lethal dose:					
Mice, 10 minute exposure:					
Milligrams per liter...	....	....	>126 [1]	....	0.4 [1]
Parts per million...	....	....	>25900 [1]	....	99 [1]
Dogs, 20 minute exposure:					
Milligrams per liter...	....	2.5 [1]	....	....	0.35 [1]
Parts per million...	....	860 [1]	....	....	86 [1]
Cats, 30 minute exposure:					
Milligram per liter...	400 [6-8]	....	120 [6-8]	....	0.20 [1]
Parts per million...	63000 [6-8]	....	25000 [6-8]	....	50 [1]
Man, 30 minute exposure:					
Milligrams per liter...	300-400 [3]	....	....	1.5 [3-7]	0.10 [1]
Parts per million...	48000-63000 [3]	....	....	1000 [3-7]	25 [1]
Kill most animals in very short time:					
Milligrams per liter...	300-400 [2-4]	2.9 [2-4]	300-400 [2]	....	....
Parts per million...	48000-63000 [2-4]	1000 [2-4]	62000-82000 [2]	....	....
Relative toxicity—CCl_4=1...	1 [8]	....	2.2 [8]	....	....
Physiological action of gas...	Asphyxiant	Respiratory irritant	Asphyxiant	Respiratory irritant	Lachrymator-respiratory irritant

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[3] Kohn-Abrest, E., Toxicological Report on Gases, Annales des Falsifications, Vol. 8, 1915, pp. 215–239.

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[5] Allison, V. C., and Katz, S. H., An Investigation of Stenches and Odors for Industrial Purposes; Jour. Ind. Eng. Chem., Vol. 11, No. 4, April, 1919, pp. 336–8.

[6] Herrmann, Georg., Wirkung Gechlorter Kohlenwasserstoffe, Chloroform, Tetrachlorkohlenstoff, Trichlorathylene, Dichlorathylene; Inaugural Dissertation. Wurzburg, Carl Fuchs, Buchdruckerei Mittere Fuhnspromenade, 1911, 50 pp.

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[8] Lehmann, K. B., Experimentelle Studien über den Einfluss technisch und wichtiger Gase und Dämpfe auf den Organismus (xvi–xxiii). Die Gechlorten Kohlenwasserstoffe der Fettreihe nebst Betrachtungen über die einphasische und zweiphasische Giftigkeit ätherischer Körper; Archieve für Hygiene, Vol. 74, 1911, pp. 1–60.

gen chloride is thus converted to sodium chloride. Carbon tetra-
chloride does not react. The total chloride produced was deter-
mined by the Mohr titration. Hydrogen chloride was computed
from the results of this and previous determinations by the
method described on page 555.

FIG. 3.
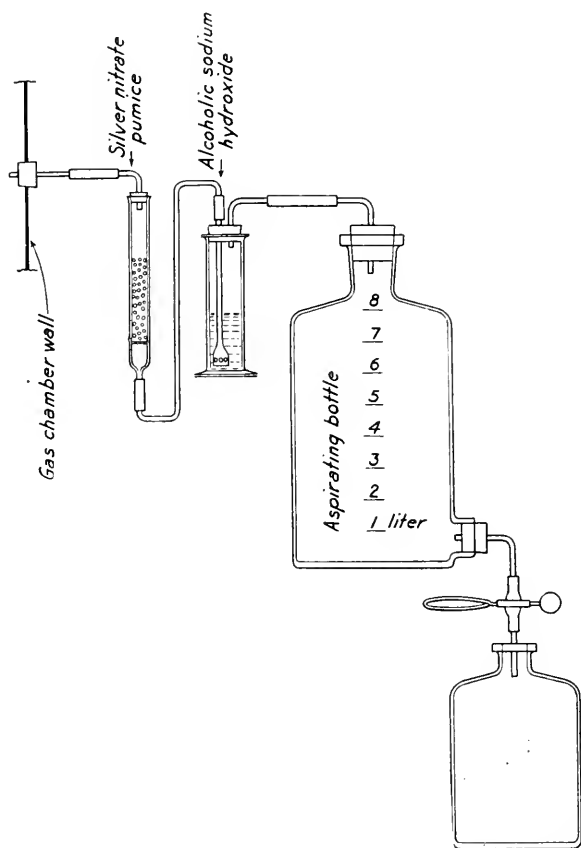
Apparatus for sampling phosgene in air of gas chamber when chlorine is absent.

Carbon Tetrachloride.—Carbon tetrachloride in the air of the
chamber was determined by absorption in activated charcoal,
and finding the increase in weight. The sample was passed
through a train of reagents, illustrated in Fig. 4, which were
placed in this order:

(a) Fused calcium chloride, 8- to 14-mesh granules, for drying the gases.

FIG. 4.
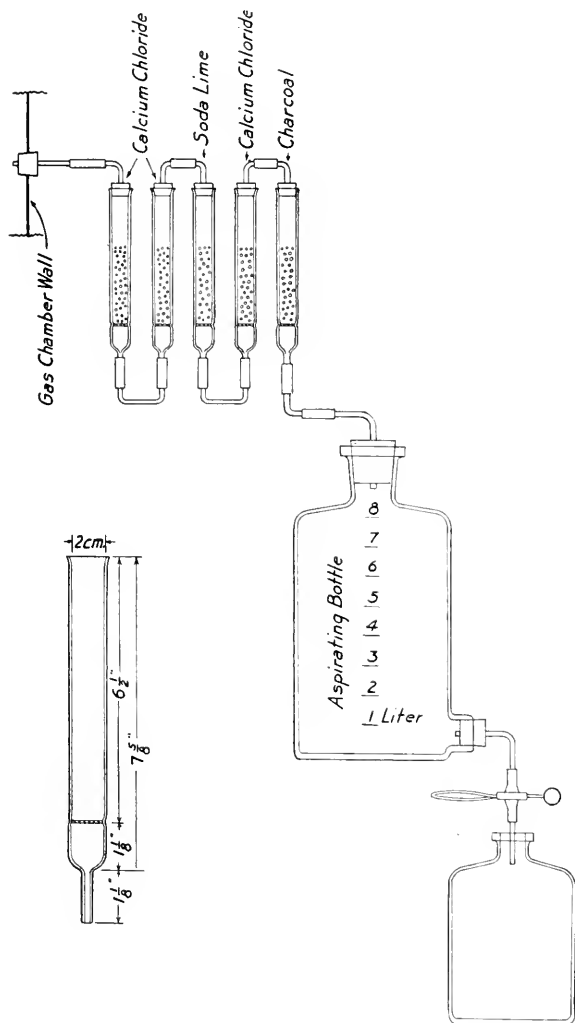
Apparatus for sampling carbon tetrachloride in air containing phosgene, chlorine and hydrogen chloride.

(b) Soda lime, 8- to 14-mesh granules, for removing phosgene, chlorine, hydrogen chloride and other acid gases from the fire.

(*c*) Calcium chloride, the same as before, to take up any moisture evolved by the soda lime.

(*d*) Charcoal, 8- to 14-mesh. The charcoal was previously dried at 105° Centigrade and accurately weighed, together with the tube which contained it, while stoppered, to prevent absorption of moisture from the air. A blank determination of the change of weight of the charcoal when pure air was aspirated through the train was made before a sample was taken. The train, except for the charcoal tube, was filled with the gas to be tested, and a measured volume was then drawn through the charcoal. From the gain in weight corrected for the blank, the proportion of carbon tetrachloride vapor in the air was computed.

Carbon Monoxide.—Carbon monoxide was determined by analysis with a Haldane apparatus in the usual gasometric way. Before the determinations, the gases containing chlorine were removed by washing in fuming sulfuric acid and then potassium hydroxide solution.

SUMMARY AND CONCLUSIONS.

As a result of the death of two men in the Navy Department from breathing fumes from carbon tetrachloride used on a fire, and the overcoming of an employee of the Bureau of Mines while fighting a fire with carbon tetrachloride liquid, an investigation of the decomposition products of carbon tetrachloride fire extinguishers was made. Experiments were conducted by two methods. The first consisted in applying the liquids to actual fires and to hot metal in a closed room of 1000-feet capacity where the gaseous products, mixed with the air, could be retained and analyzed. The second method was to pass the vapors in air through heated tubes of iron or quartz, where humidity of the air and the temperature could be controlled.

These poisonous gases were found in the air of the gas chamber: Phosgene, which is intensely poisonous, was formed in toxic quantities. Chlorine, which is also poisonous, was formed in smaller amounts. Hydrogen chloride, which is irritating and also poisonous, was formed. And there was considerable vapor of carbon tetrachloride, which is a dangerous anæsthetic. The experiments with the heated tubes substantiated the results found with actual fires, and indicated that these reactions can account for the poisonous gases:

$$CCl_4 + H_2O = COCl_2 + 2HCl$$
$$2CCl_4 + O_2 = 2COCl_2 + 2Cl_2$$
$$3CCl_4 + FeO_3 = 3COCl_2 + 2FeCl_3$$
$$2CCl_4 + Heat = C_2Cl_4 + 2Cl_2$$
$$CCl_4 + 2H_2O = CO_2 + 4HCl$$
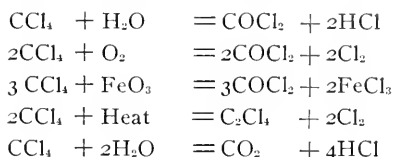
One-half of the carbon tetrachloride liquid was decomposed to poisonous gases in some of the tube experiments.

As a result of the experiments, it is recommended that carbon tetrachloride fire extinguishers be not used on fires in closely-confined spaces where conditions are such that the user cannot escape without breathing the fumes. The Army type of gas mask offers good protection from the fumes.

It is not the intention of this paper to discourage the use of carbon tetrachloride extinguishers, which are excellent for stopping incipient fires, but rather to point out a danger which can occur with their application.

The average user of a carbon tetrachloride extinguisher does not know that the decomposition products are poisonous. It would, therefore, seem that manufacturers of such apparatus should put a plainly-lettered caution plate on each extinguisher, stating that the fumes from using the extinguisher must not be inhaled, as they are poisonous.

Comparison of the Wave-lengths of a Line in a Cyanogen Band in Sunlight and of the Same Line from a Terrestrial Source. A. PEROT. (*Comptes Rendus*, July 26, 1920.)—According to the generalized theory of relativity Einstein announces that the wave-length of a line in sunlight should be 1.000002 times as great as the wave-length of the same line in light of terrestrial origin. To subject this theoretical conclusion to the test of observation a series of measurements were made at the observatory at Meudon from May 8 to June 29, 1920. The ratio was found to be 1.00000222. The real difference in wave-length is .009 Angstrom units. Care was exercised to exclude the possibility that a high pressure in the sun might be the cause of the difference. When a correction due to the vertical motion of the absorbing layer had been applied the ratio became 1.0000016. The Einstein value lies between the corrected and the uncorrected numbers.

G. F. S.

Electrolytic Production of Hydrogen Peroxide.—F. W. SKIRROW and E. R. STEIN, Research Chemists, Shawinigan Laboratories, Quebec, presented a paper at the twenty-eighth meeting of the *American Electrochemical Society* (Cleveland, September 30–October 2, 1920), giving results of investigations as to the yield of persulphuric acid by electrolyzing sulphuric acid and sodium or potassium acid sulphate, and the subsequent conversion of this acid into hydrogen peroxide. Persulphuric acid was discovered by Berthelot, and its salts first prepared by Marshall (*Trans. Chem. Soc.*, 1891, vol. lix, 771). The production of the acid by electrical methods has received much attention. The authors give references to the literature on this phase of the subject. From persulphuric acid or persulphates, hydrogen peroxide may be prepared by distillation under reduced pressure. As ordinarily conducted the loss by decomposition is large, which Price and Friend found to be due to some small impurity. In order to prevent such loss Teichner applied a modification by which disintegrated or dissolved platinum, which is the main cause of the decomposition, is removed. Löwenstein devised a continuous distillation process which separates the peroxide rapidly from the impure solution. Peitzsch and Adolph took out a British patent for the purpose but of a different type. They use pure potassium persulphate, prepared electrolytically, eliminating any incidental impurities by crystallization. They obtain a 30 per cent. solution, with almost theoretical yield. They redistill the potassium persulphate under a much reduced pressure with sulphuric acid, by which the hydrogen peroxide is distilled as fast as formed. Recently, Levin has patented a method by which the peroxide is obtained from sodium persulphate derived by electrolysis of sodium acid sulphate. Sodium persulphate being very soluble, the impurities cannot be removed by simple crystallization, but are removed by filtering through porous earthenware, the electrolyte being periodically treated with hydrogen sulphide to remove platinum and lead.

The authors give in detail their own experiments and summarize their work as follows:

Platinum so far has been the only material suitable for the anode in these operations, with possible exception of manganese dioxide. The current efficiencies of persulphuric acid, sodium or potassium persulphate show no important difference, but the sodium salt can apparently be produced to a much higher concentration than the acid without sacrifice of efficiency. Distillation of the once recrystallized potassium salt, with dilute sulphuric acid, gives reasonably high yields of the peroxide. Distillation of persulphuric acid or its sodium salt must be preceded by a rigorous purification to remove catalytic impurities.

H. L.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

MEASUREMENTS OF THE THERMAL DILATATION OF GLASS AT HIGH TEMPERATURES.[1]

By C. G. Peters and C. H. Cragoe.

[ABSTRACT.]

THE methods and results of an investigation of the thermal expansion and the chemical composition of different kinds of optical glass, chemical glassware, and commercial tubing are presented in this paper. A ring of the glass, placed between two fused quartz plates, was heated in an electric furnace and its expansion measured by the Fizeau interference method. Observations were made in the temperature regions between 20° and 650° C. on thirty-two different kinds of glass. Their dimensional changes are represented by curves which show that the glass passes through a critical expansion region, in which the expansion rate increases by two to seven times. This critical region, which for any one glass does not exceed 40°, was found as low as 400° C. with one glass and as high as 575° C. with another. About 75° above the critical region the glass softens and contracts. A comparison of results shows that the heat absorption observed by Tool and Valasek occurs in the same temperature region as the critical change in the expansion.

From these determinations of the dimensional changes of glass, the following information is obtained: the thermal expansion above and below the critical temperature, the temperature for most careful and thorough annealing, the upper limit for rapid annealing, and the region where careful cooling is essential.

RECOMMENDED SPECIFICATIONS FOR GREEN PAINT—SEMI-PASTE AND READY MIXED.[2]

[ABSTRACT.]

THIS specification for green paint—semi-paste and ready-mixed, refers to a chrome green paint, either in semi-paste pigment ground in linseed oil, or ready-mixed. The specification

* Communicated by the Director.
[1] Scientific Paper No. 393.
[2] Circular No. 97.

covers the general conditions and the maxima and minima of useful, harmful, or neutral constituents and methods of sampling, and the details as to the laboratory examination and analysis. The detailed methods of preparing the reagents to be used are also given.   The standard was prepared under the auspices of the Bureau of Standards and submitted to large numbers of representative paint manufacturers, and also recommended by the United States Interdepartmental Committee on Paint Specification Standardization.

AN EXAMINATION OF THE MUNSELL COLOR SYSTEM.
I. SPECTRAL AND TOTAL REFLECTION AND THE
MUNSELL SCALE OF VALUE.[3]

By Irwin G. Priest, K. S. Gibson and H. J. McNicholas.

[ABSTRACT.]

This paper gives the diffuse spectral reflection of twenty-four cards submitted by the Munsell Color Co., as standards of the Munsell Color System.[4]   These cards included the nine grays and three each of the following hues: red, yellow, green, blue, and purple.   The data were obtained by the following methods:

(a) Visual, Koenig-Martens Spectrophotometer for wavelengths 700 to 436 millimicrons.

(b) Photo-electric, Gibson's apparatus,[5] for wave-lengths 600 to 390 millimicrons.   In the overlapping regions, good agreement is shown between the two methods.

The " luminosities " or " total reflections " relative to magnesium carbonate in average sunlight are computed from the spectral-reflection data; and the *squares* of the Munsell " value " numbers are found to be proportional to these sunlight reflections.

The relation of the Munsell " value " scale to the natural or logarithmic scale is discussed.

Several recommendations for the improvement of the Munsell system are made with a view to the establishment of such a system on a more reliable and satisfactory foundation than exists at present.

[3] Technologic Paper No. 167.

[4] Atlas of the Munsell Color System, published by Wadsworth, Howland and Co., Boston.   Address Munsell Color Co., 220 West 42d St., New York City.   See also "A Color Notation," by A. H. Munsell, Boston, 1905, 1907, 1913, 1916.

[5] *Jour. Op. Soc. Am.*, Jan.-March, 1919.   B. S. Sci. Papers, 349, Oct., 1919.

THE COLOR AND SPECTRAL COMPOSITION OF CERTAIN HIGH INTENSITY SEARCHLIGHT ARCS.[6]

By Irwin G. Priest, W. F. Meggars, K. S. Gibson, E. P. T. Tyndall
and H. J. McNicholas.

[ABSTRACT.]

In coöperation with the Searchlight Investigation Section, Corps of Engineers, U. S. A., quantitative measurements have been made on the color and relative spectral distribution of energy in the following arcs : Sperry searchlamp arc, Columbia and Speer carbons, 75 amperes, and ordinary arc, Electra carbons, 10 amperes. The range of wave-lengths included was from 430 to 720 millimicrons.

The Koenig-Martens spectrophotometer and the Arons chromoscope were used to obtain the data. Methods of measurement are described.

In addition, the spectra of these arcs at 10 amperes, obtained with a diffraction grating, are shown, and the results of spectroscopic analysis of the carbons are given.

The data obtained are given in the form of graphs and show that there is a great excess of radiation in the blue-violet, as compared to the rest of the visible spectrum, the color of the light being *approximately* equivalent to the light of the noonday sun at Washington, but with an excess intensity in the blue.

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[6] Technologic Paper No. 168.

Water-power in Sweden. (*Chemical and Metallurgical Engineering*, September 22, 1920.)—The Swedish Government operation of water-power sites reports a gross income for 1919 amounting to 13,897,649 crowns and expenditures of 7,622,750 crowns. Nearly all the water-power plants now in operation show a profit to the government, and most of the expenditures are for additions and new construction work on power sites that have not yet been completed.

Critical Study of Methods for Detection of Methanol.—
Methanol is the name recently proposed for methyl alcohol with
a view to diminish the liability of it being used as an intoxicant.
As the detection of it even in small quantities is important, much
attention has been given to the subject and many methods sug-
gested. A. O. GETTLER has submitted fifty-eight of these to criti-
cal examination and reports the results in a paper in *J. Biol. Chem.,*
1920, xlii, 311. The methods are conveniently divided into two
groups; A, those in which the substance is converted into form-
aldehyde, and B, those in which it is tested for directly. Gettler
finds that, all things considered, the A methods are more satis-
factory. In the course of the examination over 250 liquors and
700 specimens of human viscera were tested. Improved methods
are given for detection of the substance in liquors and in tissues.
The procedure advised for its detection in liquors is as follows:

One hundred c.c. of the sample are neutralized with sodium
carbonate, using phenolphthalein, in a 200 c.c. flask and slowly
distilled until 50 c.c. of liquid is collected. This is divided into two
portions, A, of 30 c.c., and B, of 20 c.c. A is tested as follows:
100 c.c. of 10 per cent. sulphuric acid are added in a 250 c.c. dis-
tilling flask, then 6 grm. of potassium dichromate, the mixture
allowed to stand ten minutes, and then 30 c.c. distilled off slowly;
that is, requiring about one hour. This distillate contains most
of the acetaldehyde that may have been formed but very little
formaldehyde. The distillation is then resumed a little speedier,
until 60 c.c. are collected. The second distillate contains most of
the formaldehyde and very little acetaldehyde and is used for the
special tests. The special tests that have been found most satis-
factory are five color reactions and two in which crystals are
formed. The details of the procedures with these tests are given.

The methods in which the methanol is caused to unite directly
with other substances are applicable only when rather large
amounts are present. Twelve are described, most of which in-
volve long and tedious manipulations. The most satisfactory of
the series because it is simple, speedy and positive, is determina-
tion of the relation between the specific gravity and refractive
index. This relation is so characteristic that it serves to detect
methanol in common alcohol. As a color reaction the action of
hydroxylamin on potassium hydroxide is good. After long boil-
ing, cyanide is produced, ethyl alcohol, aldehyde, acetal and amyl
alcohol not being affected. The cyanide can, of course, be
easily detected.

The paper is from the Laboratory of the Pathological Depart-
men of Bellevue and Allied Hospitals, and is a most valuable con-
tribution to the solution of a problem of great importance.

H. L.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

PICKERING SPRAYS.[1]

By F. C. Cook.

[ABSTRACT.]

An investigation was undertaken to determine the efficacy of the so-called Pickering, or Pickering limewater, sprays, prepared by mixing saturated limewater with dilute solutions of copper sulphate, as compared with that of the ordinary Bordeaux sprays. The results of this investigation indicate that, on potatoes in Maine, the Pickering sprays are twice as effective as the Bordeaux mixture per unit of copper present. The stimulating and protective action exerted on potato plants was the same for each kind of spray. Pickering sprays adhered to potato leaves in practically the same degree as the standard Bordeaux, to apple leaves in a somewhat higher proportion, and to grape leaves in a lower proportion. It was shown that while Pickering sprays can not be used on tender foliage, they do not injure hardy foliage, as cranberry and potato leaves. A spray of the Pickering type, in which the limewater was replaced by barium water, gave satisfactory results.

Using these results as a basis, it is probable that the various agricultural experiment stations, as well as other interested agencies, will be able to devise formulas for sprays containing less copper sulphate than standard Bordeaux, which will be as effective as the more expensive material for certain crops.

STUDIES IN NUTRITION IV. THE NUTRITIVE VALUE OF PEANUT FLOUR AS A SUPPLEMENT TO WHEAT FLOUR.[2]

By Carl O. Johns and A. J. Finks.

[ABSTRACT.]

A diet containing bread made from wheat flour (74 per cent. extraction) when fed to albino rats as the only source of protein and water-soluble vitamine, together with an adequate

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* Communicated by the Chief of the Bureau.
[1] Bul. 866, issued August, 1920.
[2] Published in the *Jour. Biol. Chem.*, **42** (1920), 569.

inorganic salt mixture and butter fat produced only about one-third to two-thirds of normal growth.

Bread made from a mixture of 25 parts of peanut flour and 75 parts of wheat flour furnished adequate proteins and water-soluble vitamine for normal growth. A similar bread containing 15 parts of peanut flour and 85 parts of wheat flour contained proteins and sufficient water-soluble vitamine for growth at very nearly the normal rate.

Notes from American Chemical Society News Service, Bulletin 274, G. (From papers presented at the September, 1920, meeting of the Society.)—*Cheaper fuel* is indicated by the recent development of the colloidal fuel industry, a mixture of coal-dust and waste from petroleum having been found utilizable. By partially carbonizing lignite, a coke is obtained that may also be used as fuel. Comparative tests show that such half-coked material may be more economical than common coal for heating purposes. It is asserted by chemists that a large percentage of gasolin is wasted in motor vehicles by incomplete combustion.

Substitutes for cane sugar are still attracting attention. Bakers have become much interested in the new sweet-potato syrup, a process for the manufacture of which has just been developed by the Bureau of Chemistry of the U. S. Department of Agriculture. This syrup can be produced at small cost from potatoes that are of somewhat inferior quality, and, therefore, not readily marketable. Sweet potatoes of this grade are often alternated with cotton in the South in order to check the boll-weevil, and this will give a considerable supply of raw material. It is stated that the syrup is about as sweet as cane-sugar molasses, and, containing a very large amount of maltose, forms a rich brown crust on loaves and cakes in which it is used.

The substitution of glycerol for alcohol in the preparation of vanilla extract solves a problem which has been somewhat important in the present conditions.

The use of sawdust as a cattle food has been the subject of experiment in the Forest Products Laboratory in Wisconsin. By treating the waste of the buzz-saw with dilute sulphuric acid and neutralizing with lime, a soft, bran-like material is obtained, containing about 15 per cent. of water, upon which several cows fed for three months gained weight and gave more milk. The Department of Agriculture intends to experiment on a much larger scale.

Methods for the removal of ink from printed paper are under consideration by chemists interested in the cellulose industry.

H. L.

NOTES FROM THE U. S. BUREAU OF MINES.*

FUNDAMENTALS OF OIL-SHALE RETORTING.

By M. J. Gavin and Leslie H. Sharp.

The U. S. Bureau of Mines, in coöperation with the State of Colorado, is conducting investigations at the University of Colorado to obtain fundamental data on the retorting of oil shale, particularly as regards the effects of certain variable factors in retorting on the quantity and quality of the products obtained from oil shales by destructive distillation. Experiments are being conducted in a specially designed retort, in which the principal factors that affect retorting conditions can be controlled or varied at will on representative oil shales. The physical and chemical properties of the shales, and the products yielded by them, are determined in a specially equipped testing laboratory.

The following data were obtained on oil shale from DeBeque, Colorado. The shale is of the massive variety, and yields oil of 0.905 specific gravity at the rate of 42.7 gallons per ton. The weight per cubic foot of the shale is: Run-of-mine, 53.775 pounds; +1 inch, 54.775; –1 inch, 56.015; –¼ inch, 58.200. Its specific gravity is 1.92 to 2.06. The specific heat (method of mixtures, Studentia calorimeter) of the raw shale is 0.265 (mean 20–90° C.) and of the spent shale, 0.223. The heat of combustion (in oxygen in Emerson calorimeter) of the raw shale is approximately 2460 calories per gram, and of the spent shale, 600. The thermal conductivity—raw shale—between 25 to 75° C. is –0.00382.

An analysis of the shale showed: Loss at 110° C. (moisture), 0.6 per cent.; loss on ignition, 40.0 per cent.; ash or residue, 59.4 per cent. The ash analyzed 44.70 per cent. SiO_2, and 25.60 per cent. Fe_3O and Al_2O_3, 17.65 per cent. CaO, 5.28 per cent. MgO, 6.77 per cent. undetermined matter.

The character of the work and the apparatus used are outlined in a paper entitled " Investigations of Fundamentals of Oil-shale Retorting." Results of the foregoing tests, with compara-

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573

tive tables of densities, specific heats, heats of combustion, and heat conductivities of various substances, are presented in a paper entitled " Some Physical and Chemical Data on Colorado Oil Shale."

MOTOR GASOLINE SURVEY.

By N. A. C. Sm th.

It has been known that the volatility of motor gasoline manufactured for sale during the winter months is less than that of gasoline made and sold in the winter. The Bureau of Mines, in its plans to make semi-annual surveys of the motor gasoline sold in the United States, has adopted the last half of January as the most satisfactory time to take samples of winter grades, and the last half of July for those of summer grade. The second semi-annual survey has been completed and the results show a greater decrease in volatility than can be accounted for as the normal change from winter to summer quality. The explanation seems to be that in order to supply the increased demand for motor fuel, refiners have cut deeper into the crude, thus increasing the amount of high-boiling material marketed as motor gasoline.

A paper containing tables showing the results of the distillation tests and analyses has been issued by the bureau.

RECOVERY OF GOLD FROM BLACK SANDS.

By John A. Davis.

The Bureau of Mines, at its mining experiment station in Fairbanks, Alaska, is investigating methods of recovering gold from the " black sands " of placer clean-ups. A more efficient method than simple barrel amalgamation is needed for Alaskan mines, as the method oftentimes does not recover more than half the gold in the " black sand."

Tests on a magnetic black sand from a mine on Fairbanks Creek, more than 90 per cent. being magnetite and garnet, showed that 97 per cent. of the gold could be recovered by amalgamation in a barrel mill, with caustic soda added to aid amalgamation.

A black sand from St. Patrick Creek, which had been treated at the mine by amalgamation, still contained 11 cents gold per pound. Tests at the station showed that classifier concentration

and amalgamation would recover more than 80 per cent. of this gold.

The details of these tests are given in two reports entitled "Recovery of Gold from a Magnetic Black Sand," and "Recovery of Gold from Black Sand by Classifier Concentration."

MINOR NOTES.

Concentration of a Lead-zinc Tailing.—In flotation tests on low-grade complex ores of Colorado, being conducted by the Bureau of Mines, in coöperation with the State, at Golden, Colo., a locked test was made on a large sample of material from the Columbus dump at Eureka. It assayed 2.0 per cent. Pb, 3.6 per cent. Zn, 2.2 per cent. Fe, 0.28 per cent. Cu, a trace of Au, and about 1 oz. Au per ton. There was obtained a lead concentrate and a zinc concentrate. The former assayed 31 per cent. Pb, 20 per cent. Zn, 13 per cent. Fe, and 3 per cent. Cu, the recovery of lead being 75 per cent. The zinc concentrate contained 2.6 per cent. Pb, 57 per cent. Zn, 3 per cent. Fe, and 2 per cent. Cu, the recovery of zinc was low because of the proportion going with the lead. To crush the mill feed through 30-mesh is ample; the material between 30-mesh and 100-mesh fineness is then tabled to make a mixed sulphide concentrate and a low-grade tailing. By this means 48 per cent. of the mill feed is discarded. The mixed sulphide is then ground to pass 100-mesh and floated with the natural 100-mesh mill feed. This procedure gives low tailings and large mill capacity.

Hydrogen in the Coke Furnace.—In the study of conditions governing the sulphur equilibrium between gas and coke in retorting furnaces, experiments with atmospheres high in hydrogen showed that with coke containing 1.4 per cent. sulphur, hydrogen takes up 1.2 pounds per 1000 cubic feet of gas, the temperature being 900° C. but the volume of gas being computed at ordinary temperature. As the sulphur content of the coke decreases, the sulphur saturation point of the hydrogen becomes less. Observations on pure pyrite and hydrogen indicate that pyrite when heated in the presence of hydrogen is almost completely decomposed at 500° C. into H_2S and FeS, whereas without hydrogen little decomposition takes place at this temperature. At higher temperatures the hydrogen does not unite with the sulphur of the FeS formed.

The Spectrum of Hydrogen Positive Rays. G. P. THOMSON. (*Phil. Mag.*, August, 1920.)—There are two quite different spectra obtainable from hydrogen. In one but few lines are easily obtainable and the wave-lengths of these are related to one another by derivation from a common formula—the Balmer series. The other spectrum has more lines and these have not been reduced to any law. The origin of the two spectra has been in doubt. Sir J. J. Thomson's method of analyzing positive rays makes possible the separation of such rays as are due to atoms from those due to molecules and the identification of each kind.

The problem attacked by the investigator was to get positive rays consisting chiefly of hydrogen atoms and to photograph their spectrum and, again to obtain rays of molecules and examine their spectrum. He found that size and other geometrical relations of the apparatus affected the relative proportions of atoms and molecules. He succeeded in getting rays with few or no molecules. Such rays showed the Balmer series lines alone. He could not get rays of molecules exclusively. The best result attained was a marked preponderance of molecules. Then the spectrum was of the second kind with, of course, lines of the first plainly visible, agreeing with the known presence of atoms in the stream of rays. He concludes that the Balmer series spectrum is emitted by atoms and the second spectrum by molecules.

G. F. S.

An Economical Method of Utilizing the Force of the Tides. G. BIGOURDAN. (*Comptes Rendus,* July 26, 1920.)—As a result of the wanton destruction of the French coal mines by Germany the scientists of France are seeking to utilize whatever sources of energy are available in their country. In the Pyrenees and in the Alps the " white coal " of the waterfalls is largely used. The " green coal " of the tidal energy remains to be exploited, and for the industrial development of the country it is especially desirable to do this because its chief seat is in the northwest far away from the water-power of the mountains. The author renews a suggestion made by him in 1910. Let a diving bell be fixed in the water. As the tide rises the water would ascend within it and compress the enclosed air. As the tides run out there would be an aspiration of air into the bell. Both the compressed and the rarefied air could be used to transmit power. The bell would be a sort of pump in which the piston, moved by the sun and moon, makes rather more than two strokes per day. The claim is made that such an arrangement avoids the drawbacks caused by the intermittent character and the inequality of the tides and that its manipulation would be chiefly a matter of cocks and sluices requiring the services of but few attendants.

G. F. S.

THE FRANKLIN INSTITUTE.

COMMITTEE ON SCIENCE AND THE ARTS.

*(Abstract of Proceedings of the Stated Meeting held Wednesday,
September 1, 1920.)*

HALL OF THE INSTITUTE,
PHILADELPHIA, September 1, 1920.

MR. CHARLES PENROSE *in the Chair.*

The following reports were presented for first reading:

No. 2751: Radojet Air Pump.
No. 2754: Dr. W. L. R. Emmet's Work on the Electrical Pro-
pulsion of Ships.

R. B. OWENS,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, September 8, 1920.)

RESIDENT.

DR. E. H. GRAFTON, Quaker City Rubber Company, Wissinoming, Philadelphia,
Pennsylvania.

MR. PERCY S. LYON, care of H. S. B. W.-Cochrane Corporation, 17th and Alle-
gheny Avenue, Philadelphia, Pennsylvania.

MR. FREDERIC BOWERS LYSLE, Room 900, City Hall, Philadelphia, Pennsylvania.

MR. HOMER REED, JR., 700 Franklin Bank Building, Philadelphia, Pennsylvania.

NON-RESIDENT.

MR. E. GORGAS BASHORE, Rice & Bashore, Highland Building, Pittsburgh,
Pennsylvania.

MR. F. E. BRIMMER, Hydrocarbon Chemical Company, Lancaster, Pennsylvania.

MR. JOSEPH V. MEIGS, 53 Marietta Avenue, East Braintree, Massachusetts.

CHANGES OF ADDRESS.

MR. EDWIN S. BARNETT, 7011 Cresheim Road, Mt. Airy, Philadelphia, Penn-
sylvania.

MR. G. EDWARD BARNHART, 191 Marion Avenue, Pasadena, California.

MR. EDWARD BARTOW, Chemistry Department, State University of Iowa, Iowa
City, Iowa.

MR. CHARLES E. BONINE, Franklin Trust Building, 20 South 15th Street, Phila-
delphia, Pennsylvania.

MR. WILLIAM C. FARNUM, 59 Mt. Vernon Street, Fitchburg, Massachusetts.

Mr. ALEX. P. GEST, 5979 Drexel Road, Philadelphia, Pennsylvania.

Mr. WALTER F. HAGAR, JR., Keystone Screw Company, Yardley, Pennsylvania.

MISS EMILY E. HOWSON, Agnes Scott College, Decatur, Georgia.

Mr. J. C. JOHNSON, General Superintendent Transportation, Pennsylvania Railroad Company, Broad Street Station, Philadelphia, Pennsylvania.

Mr. JONATHAN R. JONES, 1800 Widener Building Philadelphia, Pennsylvania.

Mr. C. T. MACK, Doherty Men's Club, 1329 K Street, N. W., Washington, District of Columbia.

DR. LESLIE DENIS SMITH, Color Investigation Laboratory, Bureau of Chemistry, U. S. Department of Agriculture, Washington, District of Columbia.

Mr. CLINTON F. SNYDER, Minersville, Pennsylvania.

Mr. ORIN C. STOUT, 1369 East Main Street, Columbus, Ohio.

NECROLOGY.

Isham Randolph: On August 2, 1920, the engineering profession sustained an irreparable loss in the death, after a sudden and brief illness, of Dr. Isham Randolph.

Isham Randolph was born in New Market, Clark County, Virginia, in 1848. He acquired his education, especially in the engineering field, through assiduous study outside of duty hours, and through actual experience. At the age of twenty he entered the engineering profession as an axman on the Winchester and Strausburg Railroad. For the following twelve years he occupied various positions on railroad construction and operation, successively as leveler, transitman, resident engineer, assistant engineer, and roadmaster in the employ of several railroads until, in 1880, when he came to Chicago to fill the position of Chief Engineer of the Chicago and Western Indiana Belt Railway. From 1885 to 1893 he was engaged in general engineering practice with an office in Chicago. During this period he was employed by the Illinois Central Railroad as Chief Engineer to locate and build the Chicago, Madison and Northern Railroad, and the Freeport and Dodgeville Line. He also acted as Consulting Engineer for the Union Stock Yards and Transit Company, and the Baltimore and Ohio Railroad Company.

On June 7, 1893, he was appointed Chief Engineer of the Chicago Sanitary and Ship Canal (the Chicago Drainage Canal). He directed this large enterprise for fourteen years, from almost its very beginning to its final completion. This artificial channel is second only to the Panama Canal in size, and its cost was around sixty millions of dollars. Its construction was marked by excellent progress and efficiency throughout until its final successful completion. This great work contributed largely to Isham Randolph's fame as engineer. It was recognized by the Paris Exposition of 1900 by awarding him a gold medal.

While engaged on this work he was appointed by President Roosevelt to act as a member of the Board of Consulting Engineers for the Panama Canal, and was one of the five members of the Board whose minority report was accepted by the President and Secretary of War and adopted by Congress, and in accordance with which the Canal has been
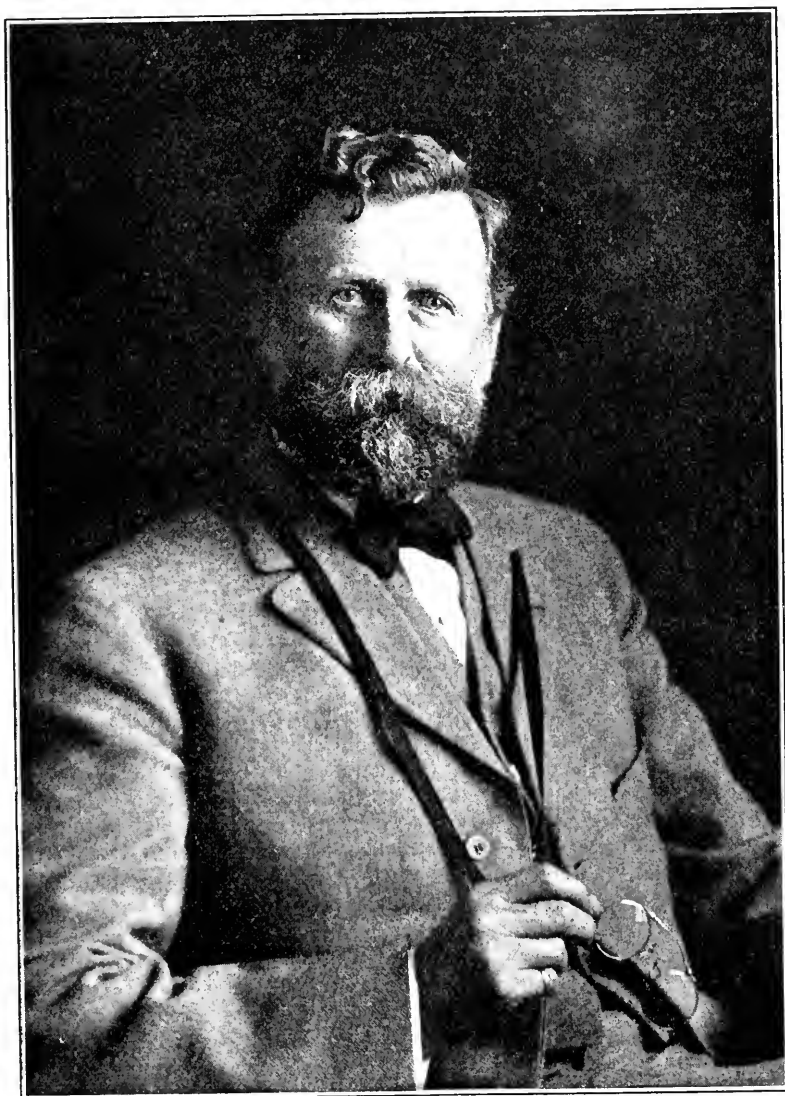
ISHAM RANDOLPH
1848-1920

completed. In 1908 he was one of the six engineers invited by President Roosevelt to accompany Mr. Taft, then President-elect, to Panama to consider: " Whether or not there is any reason to change the plans upon which we are now working." This Board in its report of February 16, 1909, upheld unanimously the plans for a lock canal as now built. It will be remembered that the majority of the original commission consisting of some of the most eminent American and European engineers, recommended a sea-level canal. Subsequent experience with the Culebra Cut proved the wisdom of the minority report.

The Obelisk Dam above the Horseshoe Falls of the Niagara River was designed and built by him. It was built on end on the river bank, like an obelisk, and then tilted over into the rapids. The operation was entirely successful.

He served on numerous commissions either as chairman or member. The following are only a few of the positions he occupied:

Chairman of the Internal Improvement Commission of Illinois, which made plans for a canal from Lockport, Ill., to Utica, Ill., including hydro-electric power development of 140,000 horsepower.

Member of the Illinois State Conservation Commission, examining and reporting on the conservation of the national resources of the State.

Member of the Rivers and Lakes Commission of Illinois, which has jurisdiction over the rivers and lakes of the State.

Member of the Chicago Harbor Commission, which made a report and prepared plans for a lake-front harbor in Chicago.

Member of the Water Supply Commission of the City of Toronto, which made complete plans for a new water supply and water works system for that city.

Chairman of the Florida Everglades Engineering Commission, reporting to the State of Florida on the drainage of Everglades swamp lands.

In this instance he was under a personal contract with the State and employed the other members of the Commission. The completed report was submitted to the Governor and made public.

He made a study and prepared a report and plans for a commercial harbor for the City of Milwaukee, Wis. He was Consulting Engineer on track elevation for the cities of Baltimore, Md., and Toronto, Canada. He was Consulting Engineer for the Little River Drainage District of Cape Girardeau, Mo., advising on the plans for the drainage of some 500,000 acres of land.

Doctor Randolph was a member of the American Society of Civil Engineers, Past President and member of the Western Society of Engineers, Member of the American Association of Engineers, The Franklin Institute, the Illinois Society of Engineers and the British Royal Society of Arts.

The above list, although far from complete, is sufficient to show the high standing in the engineering profession which Doctor Randolph occupied, and the unlimited confidence of the public he enjoyed, for the name of Isham Randolph attached to any enterprise was a guarantee of honesty, integrity and technical efficiency.

On June 15, 1910, the University of Illinois conferred upon him the

degree of " Doctor of Engineering," the Washington and Lee University, of Virginia, conferred upon him the degree of " Doctor of Commercial Science," and in February, 1913, The Franklin Institute of Philadelphia, Pennsylvania, conferred upon him the " Elliott Cresson Medal," the highest award in the gift of the Institute, " In recognition of Distinguished Achievements in the Field of Civil Engineering."

During the great war, Isham Randolph proved himself to be an ardent patriot. He was President of the Citizens' Unit of the 108th Engineers, and largely instrumental in organizing it. He made, entirely without compensation, confidential inspection of several military camps and reported thereon to the Secretary of War.

Coupled with this remarkable record of professional and social activities were Isham Randolph's personal qualities, which made it a great privilege to know him and which made him beloved of all who came in close touch with him. A heart most kind and generous, a mind most cultured and subtle, a soul most noble.

RALPH MODJESKI.

Benjamin Smith Lyman, geologist, mining engineer and inventor, was born at Northampton, Massachusetts, December 11, 1835, and died at Cheltenham, Pennsylvania, August 30, 1920. His educational training was begun in his native city, and in 1855 he was graduated from Harvard University, receiving the degree of Bachelor of Arts. He spent three years at the School of Mines, in Paris, and two years at the Royal Academy of Mines, in Freiberg, Saxony. His professional career began as Assistant State Geologist of Iowa, in 1858. After devoting several years to private geological work he was appointed mining engineer under the Public Works Department of the Government of India, giving special attention to the surveying of oil fields. From 1873 to 1879 he was Chief Geologist and Mining Engineer to the Government of Japan. In 1887 he was appointed one of the Assistant Geologists of the Second Pennsylvania Geological Survey and served in this capacity for nine years. He made geological excursions through the United States, British America, India, China, Japan, the Philippines and many parts of Europe. He was the author of over 150 papers on Geology, Geological Surveying and other subjects. Mr. Lyman was a member of over twenty-five of the leading scientific and technical societies of the world. He became a member of The Franklin Institute in 1890, and for a number of years was very active on its Library Committee, serving two years as its Chairman.

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BOOK NOTICES.

FUEL OIL IN INDUSTRY. By Stephen O. Andros, A.B., E.M. Formerly Assistant Professor of Mining Research, Engineering Experiment Station, University of Illinois. 241 pages, contents and indexes, 8vo. Chicago, The Shaw Publishing Company, 1920. $3.75.

The fuel problem has become most serious in recent years, not only from the enormous extension of power and heating plants, but from the uncertain condition in the labor relations in the great mine-fields. Investigations seem to show that the available coal supply is ample for many years, and that extensive areas are likely to be found in unexplored or partly explored parts of the world, but the getting out of the material is becoming increasingly difficult. Coal mining is a hard and dangerous occupation; the mortality and morbidity figures even under the most advanced safety systems are distressingly high. In this emergency, engineers have turned

to several methods for substitution of the old-fashioned furnace firing. One method that is attracting considerable attention is the use of powdered fuel. This materially increases the heat obtainable from a given weight of coal, simplifies the labor problem somewhat and reduces the cost of ash disposal, but the practical application is still not widely accepted. Water power—the "white coal" of the European engineers—has offered an excellent substitute for fuel, but such power is not available in all parts of the world, and its application usually involves considerable expense for plant. Incidentally, the use of such power will in many cases destroy beautiful scenery, a result which may here and there provoke active opposition, though usually the "pocket nerve" ultimately wins out.

A decided drift towards the use of fuel oil has set in lately, and it seems from the statement of the book in hand to be applicable to all important types of power and heating plants. Many forms of such plants are described, tabular information given as to relative costs of solid and liquid fuels, analytic data in considerable amount and numerous illustrations of plants, details of construction and accessory apparatus. The book presents in compact and convenient form a large amount of information of use to the power-plant and heating-plant engineer and is a timely addition to the literature of the subject. A specially interesting chapter is on "Colloidal Fuel," being an abstract from a paper read before the American Society of Mechanical Engineers, by L. W. Bates. This form of fuel is a suspension of pulverized coal in fuel oil, under conditions which prevent rapid separation of the two phases. It is produced in several forms of somewhat different consistence. It would seem that such a mixture would solve one of the objections that have been brought against the use of pulverized fuel, namely, the liability to spontaneous combustion, since the particles of coal are completely protected from air by the oil.

The literary quality of the book is not as high as it should be. Such spelling as "electrolite," which occurs several times, and the use of such terms as "benzole" indicate that carelessness of nomenclature which is too common in American works on applied science. The work will be very useful to the fuel engineer.

HENRY LEFFMANN.

CHEMICAL FRENCH. An Introduction to the Study of French Literature. By Maurice L. Dolt, Ph.D. Second edition, 8vo., 413 pages. The Chemical Publishing Company, Easton, Pa., 1920.

The first edition of this book was reviewed in this JOURNAL, and little need be added to the criticisms there made. The purpose and method of the work are excellent, and the material presented is interesting and profitable to both beginners and those who have good knowledge of the French language. Two essays have been added in the present edition, one by Le Chatelier and one by Haller. These additions have disturbed somewhat the paging of the book, and thrown the latter part of the table of contents into confusion.

The book contains a good deal of information on French grammar, including a table of the principal parts of the more important irregular

verbs and explanation of many idioms. The selections for advanced reading, consisting of original articles by distinguished chemists, represent a wide range of subject and of date, the earliest being a paper by Becquerel and one of the most recent a paper by Madame Curie.

HENRY LEFFMANN.

ELECTROMETRIC METHODS AND APPARATUS FOR DETERMINING HYDROGEN-ION CONCENTRATIONS. Catalogue 75, 39 pages, illustrations, quarto. Philadelphia, Leeds and Northrup Company, 1920.

A special interest attaches to this publication which deserves notice, namely, the explanation of the general principles of hydrogen-ion concentration and of the methods best adapted to the determination of the same. The subject is distinctly mathematical. Twenty-six pages are devoted to theory and practice and two pages of bibliography follow. Attention is called to the irregularity of the symbol used for hydrogen-ion concentration, which is often written pH, Ph or p_H. The proper form is stated to be p_H.

Inasmuch as the old methods with indicators fail to give trustworthy results in many cases, electrical methods have come in extensive use, which give the actual or effective reaction of solutions as distinguished from the total reaction. The principles upon which these measurements are made are explained in much detail and the several forms of apparatus of precision employed for the operations described. Two pages of bibliography, including about fifty representative contributions on the subject, are added.

HENRY LEFFMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS. Report No. 68, A Study of the Effect of Kiln Drying on the Strength of Airplane Woods. Preprint from Fifth Annual Report. 69 pages, illustrations, plates, quarto. Washington, Government Printing Office, 1920.

The belief that kiln drying necessarily makes wood brash or "takes the life out of it" is discredited.

The report contains the results and discussion of tests on fourteen of twenty-six species tested at the Forest Products Laboratory, Madison, Wis., to find the effect of kiln drying on strength.

The chief conclusions are:

Proper kiln drying produces material fully equal to carefully air-dried stock.

Through improper kiln drying wood may have its strength properties, particularly its toughness or resistance to shock, seriously damaged without visible evidence of such damage.

The effect of a given kiln-drying process is not the same on all species.

Safe limits of temperature and relative humidity to be used in drying the several species are given.

Report No. 85, Moisture Resistant Finishes for Airplane Woods. 8 pages, illustrations, plate, quarto. Washington, Government Printing Office, 1920.

This report describes briefly a series of experiments made to determine the comparative moisture resistance of linseed oil, impregnation treatments, condensation varnishes, oil varnishes, enamels, cellulose varnishes, rubber, electroplated and sprayed metal coatings, and metal-leaf coatings when applied to wood.

All coatings except the rubber and electroplated metal coatings, which were not developed sufficiently to make them practical, admitted moisture in varying degrees. The most effective, and at the same time most practical, coating was found to be that of aluminum leaf.

Report No. 87, Effects of Nature of Cooling Surface on Radiator Performance. 13 pages, illustrations, quarto. Washington, Government Printing Office, 1920.

A discussion of the effects of roughness, smoothness and cleanness of cooling surfaces on the performance of aeronautic radiators, as shown by experimental work, with different conditions of surface on (1) heat transfer from a single brass tube and from a radiator, (2) pressure drop in an air stream in a single brass tube and in a radiator, (3) head resistance of a radiator, and (4) flow of air through a radiator. It is shown that while smooth surfaces are better than rough, the surfaces usually found in commercial radiators do not differ enough to show marked effect on performance, *provided the surfaces are kept clean*.

Report No. 88, Pressure Drop in Radiator Air Tubes. 11 pages, illustrations, plates, quarto. Washington, Government Printing Office, 1920.

A description of a method for measuring the drop in static pressure in air flowing through a radiator, and shows (1) a reason for the discrepancy noted by various observers between head resistance and drop in pressure, (2) a difference in degree of contraction of the jet in entering a circular cell and a square cell, (3) the ratio of internal frictional resistance to total head resistance for two representative types, (4) the effect of smoothness of surface on pressure gradient, and (5) the effects of supplying heat to the radiator on pressure gradient.

The fact that the pressure gradients are found to be approximately proportional to the square of the rate of flow of air appears to indicate turbulent flow, even in the short tubes of the radiator.

Report No. 91, Nomenclature for Aeronautics. 41 pages, illustrations, plates, quarto. Washington, Government Printing Office, 1920.

The nomenclature and list of symbols were approved by the Executive Committee of the Committee for publication as a technical report on April 1, 1920, on recommendation of the Subcommittee on Aerodynamics.

The purpose of this report is to secure uniformity in the official documents of the Government and, as far as possible, in technical and other commercial publications.

The stability terms were referred for special consideration to Messrs. E. B. Wilson, J. C. Hunsaker, A. F. Zahm, E. P. Warner and H. Bateman. and the power-plant terms were referred to the Sub-Committee on Power Plants for Aircraft.

Copies of the above reports may be obtained upon request from the Committee.

PUBLICATIONS RECEIVED.

Marine Engineers' Handbook, prepared by a staff of specialists. Frank Ward Sterling, Editor-in-chief. 1486 pages, illustrations, 12mo. New York, McGraw-Hill Book Company, 1920.

Fuel Oil in Industry, by Stephen O. Andros, A.B., E.M. 274 pages, illustrations, 8vo. Chicago, The Shaw Publishing Company, 1920. Price, $3.75.

Ontario Department of Mines: Twenty-ninth Annual Report. 41 pages, illustrations, 8vo. Toronto, King's Printer, 1920.

U. S. Coast and Geodetic Survey: Terrestrial Magnetism. Results of Magnetic Observations Made by the Survey in 1919 by Daniel L. Hazard. Special Publication No. 64. 27 pages, 8vo. Washington, Government Printing Office, 1920.

Bureau of Standards: Scientific Paper No. 381. An Electron Tube Transmitter of completely modulated Waves, by Lewis M. Hull, Associate Physicist. 13 pages, illustrations, 8vo. Washington, Government Printing Office, 1920. Price, 5 cents.

Bureau of Mines: Bulletin 182, Casing Troubles and Fishing Methods in Oil Wells, by Thomas Curtin. 48 pages, illustrations, plates, 8vo. Monthly Statement of Coal-mine Fatalities in the United States, May, 1920, by W. W. Adams. 8 pages, 8vo. Technical Paper 230, Determination of Molybdenum, by J. P. Bonardi and Edward P. Barrett. 35 pages, 8vo. Technical Paper 233, The Properties of Some Stoneware Clays, by H. G. Schurecht. 41 pages, diagrams, plates, 8vo. Technical Paper 238, Indicators for Carbon Dioxide and Oxygen in Air and Flue Gas, by L. H. Milligan, D. O. Crites, and W. S. Wilson. 23 pages, illustrations, plates, 8vo. Washington, Government Printing Office, 1920.

U. S. Department of Agriculture: Circular 112, Timber Depletion and the Answer. A Summary of the Report on Timber Depletion and Related Subjects, Prepared in Response to Senate Resolution 311. 16 pages, 8vo. Washington, Government Printing Office, 1920.

Application of the Spectrograph to Detection of Powerful Drugs. F. Twyman (*Analyst,* 1920, xlv, 303) has had much success in the detection of certain substances by means of absorption bands. Minute amounts of strychnine, cocaine, phenol, pyridin, and benzoic acid have been so detected. Twyman does not give any details as to the arrangement or operation of the apparatus.

H. L.

Altitudes in Florida. (*U. S. Geological Sur. Press Bull. No. 456,* August-September, 1920.)—The highest point in Florida whose altitude has been determined is Iron Mountain, in Polk County, which stands 325 feet above sea level. The average elevation of the State as computed by the Geological Survey is about 100 feet.

CURRENT TOPICS.

The Arrangement of Atoms in Crystals. W. LAWRENCE BRAGG. (*Phil. Mag.,* August, 1920.)—Thanks to the study of the effects of crystals upon X-rays it is now possible to state the exact arrangement of the atoms within many crystals. For example, in a crystal of sodium chloride the sodium atoms are at the corners and face-centres of a cube while the chlorine atoms are at the middle points of the cube-edges and at the centre of the cube. It is found that the relations within a crystal are geometrically represented by an assemblage of tightly packed spheres, whose centres coincide with the centres of the atoms and, further, that it is possible to assign to the sphere of the atom of any element a definite and characteristic diameter, at least within certain limits. The unit of length employed is the hundred-millionth of a centimetre.

The method of fixing the diameters of the atoms is this. Hull has studied metallic iron and has interpreted the diffraction effects of this metal upon X-rays to mean that the distance between the centres of adjacent atoms is 2.47 units. Moreover, by the same general method the arrangement of the sulphur and iron atoms in iron pyrites is known. About each atom of iron in the crystal complex let a sphere be described of 2.47 units diameter. Into this let other spheres be fitted with their centres at the centres of the sulphur atoms. The diameter which must be given to these spheres to make them touch the adjacent spheres is taken as the diameter of the sulphur atom and equals 2.05 units. By the use of the sphere-plot a certain parameter for pyrites was calculated to be .22, whereas the diffraction pattern led to the closely agreeing value of .226.

From a knowledge of the structure of zinc sulphide and of the diameter of the sulphur atom, determined as just explained, the diameter of the zinc atom is calculated to be 2.65 units. Then with the dimensions of the zinc atom as a known quantity zinc oxide is studied and the diameter of the oxygen atom is found to equal 1.30 units. The sulphur atom thus seems to be larger than the oxygen atom, and the distance from the zinc atom to the sulphur atom in zinc blende is 2.35 units. If oxygen be substituted for the sulphur, the distance from a zinc to an oxygen atom is only 1.97. This shows that the radius of the sulphur atom exceeds that of the oxygen atom by .38 units. A dimensional study of the oxides and sulphides of magnesium, calcium, silicon and barium brings out that in all these compounds the atomic radius of sulphur is longer than the corresponding dimension for oxygen.

The differences are .43, .37, .36 and .39 units, respectively. A similar investigation of halogen salts leads the author to conclude: " The replacement of fluorine by chlorine, chlorine by bromine, and bromine by iodine, increases the dimensions of the structure by an approximately constant amount."

A table of atomic diameters is given for thirty-eight elements, and these diameters are made the ordinates of a curve with the atomic numbers of the elements as abscissas. " The atomic diameters lie on a curve resembling Lothar Meyer's curve of atomic volumes. The alkali metals head each period with the greatest diameter, followed by the alkaline earths. The diameter diminishes steadily as the atomic weight is increased, reaching a minimum for the electronegative elements at the end of the period. In other words, when the atomic arrangement of compounds is taken into account, the periodic relation between the atomic volumes shown by Lothar Meyer's curve can be extended to the compounds of the atoms."

The author discusses the empirical relations he has derived in the light of the theory of atomic structure proposed by Lewis and amplified by Langmuir. According to this the small diameter of the electronegative elements is due to two such atoms in a crystal sharing electrons and of necessity being close together, while electropositive atoms do not have electrons in common with other atoms and are thus not near to them. The relative simplicity of the linking of electropositive atoms to each other indicates the reason for the crystallizing of electropositive elements in the cubic or hexagonal systems. It is reasonable, on the other hand, for the electronegative elements with some of their electrons shared by two atoms to crystallize in more complicated forms.

G. F. S.

The Dissociation of Iodine Vapor and Its Fluorescence. S. LANDAU, WARSAW, and E. STENZ. (*Phil. Mag.*, August, 1920.)— R. W. Wood has investigated the fluorescence of the vapors of sodium, mercury, and iodine. He discovered in them the remarkable property of optical resonance. The absorption spectrum of iodine vapor contains from 40,000 to 50,000 lines. When light of different wave-lengths falls upon the vapor and makes it fluoresce, the spectrum of the light emitted by the vapor is found to vary with the incident light. The investigators proposed to themselves in effect the question, " Is the complex relation between the incident and the emitted fluorescent light due to something in the structure of the molecule of iodine or does it inhere in the atom?"

It was found that an elevation of temperature has less effect than has been thought upon fluorescence. The authors observed this even at a vapor temperature of 825° C. When iodine vapor at a pressure of .25 mm. of mercury was raised to something above

1000°, fluorescence gradually disappeared. It reappeared as the vapor cooled down.

Dissociation of the iodine molecule and disappearance of fluorescence go hand in hand. For such pressure and temperature that dissociation was complete there was an entire lack of fluorescence, and of resonance spectra as well. " Thus the complicated system, corresponding to the thousands of absorption lines in the visible part of the spectrum, is not inherent in the atom, but in the molecule. The structure of the atom should be relatively simple."

A foot-note is not without interest: " During the war (and even now) it was impossible to receive regularly scientific journals at Warsaw; the authors excuse themselves for having perhaps omitted some papers concerning the question treated."

G. F. S.

Standardization of Disinfectants. A. L. WALTERS (*Amer. Jour. Pub. Health,* vol. vii, through *Lilly Scient. Bull. Ser. 1, 369*) criticises unfavorably the implicit reliance on the phenol coefficient as advocated by the Hygienic Laboratory, pointing out that different organisms react differently under standard methods of testing. He refers especially to the different action of a certain " Pine Oil Disinfectant " made according to a Hygienic Laboratory formula. Experiment showed that while according to the official method (using cultures of *B. typhosus*) this preparation has four times the power of phenol, when tested against cultures of *Staphylococcus aureus* the action was far less than that of phenol. Walters points out that the true value of a disinfectant can only be stated in terms of the organism or organisms on which it is to be used in actual practice. To state that Pine Oil Disinfectant is " an efficient liquid disinfectant " which " may be used wherever the ordinary coal-tar compounds are used " is certainly drawing erroneous conclusions from a phenol coefficient determination. In no case has the practical value of this dictum been so clearly exemplified as in the present investigation. Based on the report of Stevenson from the Hygienic Laboratory entitled " An Efficient Liquid Disinfectant," one would be led to think that " Pine Oil Disinfectant " is four to six times as effective a germicide as phenol, without any exceptions. That this is not the case has been clearly shown by the preceding experiments and contrary to the statement in the above report, Pine Oil Disinfectant cannot be satisfactorily used to replace the ordinary coal-tar compounds commonly employed as disinfectants.

The paradoxical action of pine oil in being markedly more germicidal than phenol on the typhoid bacillus and decidedly less germicidal on the staphylococcus is an interesting phenomenon deserving further study, and is apparently illustrative of specificity in disinfectants.

Unusual Minerals Mined in 1919. (*U. S. Geological Sur. Press Bulletin No. 456,* August-September, 1920.)—If the casual reader ran across the words lepidolite and amblygonite in a theological paper he might mistake them for the names of tribes of the Philistines; if he found them in a paper on fossil skeletons he might suppose they meant some kinds of armored reptiles that ranged the swamps of the Cretaceous period. A companion word, spodumene, though it ends with " mene," would mean nothing to him. Lepidolite, amblygonite, and spodumene are the names of the most abundant lithium minerals—minerals that are used as sources of the salts of lithium, one of the chemical elements. Lithium suggests a mineral water or salts used for the treatment of rheumatism. But that is another story. A large percentage of the lithium minerals mined is made into lithium for use in storage batteries of a certain type. Lithium salts and lepidolite are added to glass " batches " to reduce the viscosity of the melted glass—that is, to make it flow more freely. Lithium chloride has been used to some extent in fireworks and signal lights, to which it imparts an intense red color.

Most of the lepidolite mined in the United States is taken from a deposit near Pala, San Diego County, Calif., and most of the amblygonite is mined in South Dakota, where it occurs in masses weighing hundreds of pounds. Practically all the spodumene produced in the United States is mined in the Black Hills, in South Dakota, where it occurs in immense crystals, some of them more than 30 feet long.

Lithium minerals amounting to 6287 short tons, valued at $115,-000, were produced in the United States in 1919—more than ten times as much as was produced in any year before 1916.

Deterioration of Nickel Resistors.—F. A. J. FITZGERALD and GRANT C. MOYER of the Fitzgerald Laboratories, Inc., presented at the thirty-eighth meeting of the *American Electrochemical Society* (Cleveland, September 30th–October 2nd) a communication showing that, under certain precautions, pure nickel wire is applicable as a substitute for the nichrome alloy now much used. This alloy is expensive and certain onerous conditions are attached to a license for its use. Nickel has a high thermal coefficient of electric resistance and a liability to oxidation, but it was thought that these disadvantages could be overcome. Tests, however, showed early deterioration, by the wire becoming brittle, although no marked oxidation had occurred. It was thought at first that the result was due to absorption of carbon, as the insulating material was infusorial earth and a refractory cement, both of which contained organic matter. Some of the brittle wire was tested by being heated in a current of oxygen and it was found that the emitted gas produced a precipitate of barium carbonate. The inference, however, was not correct, and details are given of experi-

ments by which it was proved that combination with sulphur is the cause of deterioration.

From the experiments it appears that:

Sulphur makes nickel brittle at low temperatures.

Nichrome wire is also affected by sulphur but less markedly.

Wire rendered brittle by sulphur can be softened by heating in a current of oxygen. Pure nickel seems to stand up well as a resistor when not exposed to contamination with sulphur.

H. L.

Ferrocerium.—Alcan Hirch, in a paper presented at the General Meeting of the American Electrochemical Society, in April, 1920, presents interesting data in regard to the pyrophoric alloys of cerium and iron. At first these were merely matters of curiosity, but their manufacture has now grown to be an important industry. During the recent war, pyrophoric lighters formed part of the equipment of every soldier, particularly the form termed " fuse " or " wind " lighter. The " iron match " as Hirch calls it, is steadily replacing the wooden match, among the advantages of the former being its general safety and the saving in bulk.

The cerium alloy depends on the residues from the gasmantle industry. Formerly these residues were considered waste products, but the entire output is now utilized in the manufacture of flaming ores, special glass, and the pyrophoric alloys. A brief outline is given of the methods of making the alloys, the author stating that the process, which is electrolytic, is one of the most peculiar known. The starting point is a mass of metals of the cerium group. This is soft but tough, can be cut by a strong knife and is not pyrophoric. This mass is melted and alloyed with iron, the latter forming about one-third the mixture. Other alloys can be prepared which give flame or a shower of sparks. Magnesium and zinc are used for special purposes. The pyrophoric quality depends on the brittleness of the alloy and its low kindling point. Metals of the cerium group have a very high affinity for oxygen. The three properties of low melting point, high affinity for oxygen and nitrogen, and high density seem to indicate valuable applications for deoxidizing molten metals. The author gives some data from experiments in this line.

H. L.

Journal

of

The Franklin Institute

Devoted to Science and the Mechanic Arts

THE ANNEALING OF GLASS.*

BY

L. H. ADAMS and E. D. WILLIAMSON.

Geophysical Laboratory, Carnegie Institution of Washington.

INTRODUCTION.

Definition of Annealing.—It is well known that quickly cooled glass is in an unstable condition due to stresses acquired in cooling. Such glass is said to be " strained," and if the strain is excessive, the glass may crack or even fly to pieces when handled, or when heated or cooled. If the strained glass be heated to a sufficiently high temperature and then slowly cooled, it may lose a considerable part of its internal stress. This operation of removing or diminishing the strains in glass is called annealing. It should be noted that this is not the only use of the word annealing, which is often applied to other kinds of transformations. A metal such as silver when drawn, hammered or otherwise deformed, undergoes a physical change and acquires increased hardness which it may lose when heated. It is then said to be annealed. " Annealing " is also used to characterize the chemical and physical changes taking place in the complex mixture, steel, when it is heated to certain temperatures. In the present discussion, however, we use the term annealing only in connection with the relief of internal stress, a process which has no necessary connection with the other above-mentioned physical processes.

Reason for Annealing of Glass.—The removal or prevention

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* Communicated by Dr. Arthur L. Day, Director of Laboratory.

of excessive strain is one of the many difficult problems encountered by the glassmaker. When glass is poorly annealed large losses by breakage may occur during the customary cooling process, and even if the glass has been completely cooled without fracturing, it may show an annoying liability to breakage when handled at some subsequent time. A proper and efficient method of annealing is therefore a necessary part of the manufacture of glass of any kind, and is of very highest importance in dealing with optical glass.

While commercial glassware such as plate glass, window glass, bottles, chemical glass, cut-glass and so forth must be free from excessive strain, optical glass requires a much more complete and perfect annealing process. Quite apart from the loss due to breakage, strain in optical glass is to be avoided since it may cause the surface of lenses and prisms made from the glass to warp or distort,[1] thus spoiling the optical definition.

Lack of Data on Annealing.—Our attention was first directed toward this subject in 1917 when the Geophysical Laboratory was called upon to develop methods for the various operations involved in the manufacture of optical glass. In the early part of that year little was known in this country about the making of optical glass. The compositions of most of the important glasses were available,[2] some progress had been made at three or four places in evolving the technic of melting, but the sum total of known facts was very small, and concerning the annealing of optical glass or any other kind of glass the lack of definite information was especially striking. Schott,[3] in 1891, had determined for several glasses the lowest temperature at which an undoubted diminution of stress took place within twenty-four hours, and more recently Zschimmer and Schulz[4] had investigated the amount of stress produced in glass by cooling it suddenly from various temperatures, but altogether the published records up to the year 1917 contain practically nothing on which to base a rational schedule for the annealing of glass. Therefore when confronted with the problem of annealing the vast quantities of

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[1] See H. Hovestadt: " Jena Glass," p. 15.

[2] See, for example, Zschimmer's tables in Doelter's " Handbuch der Mineralogie."

[3] O. Schott: *Z. Instrumentenkunde* **11**, 330–337 (1891).

[4] E. Zschimmer and H. Schulz: *Ann. Phys.* (4) **42**, 345–396 (1913).

optical glass required for military and naval instruments, the
first step necessarily involved a systematic study of the annealing
process, in the factory and in the laboratory, and a quantitative
determination of various factors such as the temperature for best
annealing, the allowable cooling rates, and the relation between
strain and temperature gradient. Experimental work on anneal-
ing was done by several members of the scientific staff of the
Geophysical Laboratory. G. W. Morey and F. E. Wright carried
out investigations at the plant of the Bausch and Lomb Optical
Company; W. P. White at the Geophysical Laboratory; H. S.
Roberts, L. H. Adams and E. D. Williamson at the Charleroi
plant of the Pittsburgh Plate Glass Company; and the last two
also at the Geophysical Laboratory. The application of the results
to the actual annealing of optical glass on a large scale in the
factories [5] has met with entire success.

Previous publications of this Laboratory have already pre-
sented details concerning certain subsidiary problems [6] bearing
upon this subject, and it now remains to describe the annealing
process and to correlate the results of the earlier investigations.

The Generation and Release of Strain.—Before describing the
method used by the authors in determining the proper procedure
for annealing glass, it is desirable to consider in a general way
the generation and release of internal stress.[7] Glass is an amor-
phous material which at ordinary temperature is as hard and
rigid as a typical solid, but when heated it gradually softens as

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[5] During the war over 600,000 pounds of optical glass was delivered
to the U. S. military establishment, and of this amount over 95 per cent.
was manufactured under the direct supervision of various members of the
scientific staff of the Geophysical Laboratory.

[6] See, for example, E. D. Williamson and L. H. Adams: Temperature
Distribution in Solids During Heating and Cooling, *Phys. Rev.,* 14, 99–114
(1919); L. H. Adams: Tables and Curves for Use in Measuring Tempera-
ture with Thermocouples, *Trans. Am. Inst. Min. Met. Eng.,* 2111–2124 (1919) ;
E. D. Williamson and H. S. Roberts: Thermocouple Installation in An-
nealing Kilns for Optical Glass, *Ibid.,* 1445–1453; E. D. Williamson: Strains
Due to Temperature Gradients, with Special Reference to Optical Glass,
J. Wash. Acad. Sci., 9, 209–217 (1919) ; L. H. Adams and E. D. Williamson:
The Relation Between Birefringence and Stress in Various Types of Glass,
Ibid., 9, 609–623 (1919).

[7] The word stress commonly denotes a force per unit area, and strain
a relative deformation. Since stress usually accompanies strain, the two
words are often used interchangeably, but it is important to bear in mind
that they are not synonymous.

the temperature is raised, until it becomes a viscous and finally a thin liquid. During cooling the reverse process takes place, the glass changing without discontinuity from a thin liquid to a rigid " solid." This range of temperature through which occurs a continuous " solidification " of a single phase, is peculiar to undercooled liquids and is never observed with crystalline solids.

Suppose now that a flat plate or slab of glass, originally free from stress and of a uniform and comparatively low temperature, is heated at both faces—that is, at the two surfaces normal to the shortest dimension of the piece. The outside layers being hotter, tend to expand more than the inner, but this tendency is to a certain extent resisted by the inner layers; that is, the surfaces of the slab are not free to expand the normal amount and will therefore be under longitudinal compression—compression in all directions parallel to the faces of the slab. At the same time the innermost layer will be stretched by the outer layers and will be under tension.[8] Furthermore, the longitudinal stress changes continuously from a compression at the surface to a tension in the middle, and therefore at a certain distance below the surface there will be a layer with no stress, *i.e.*, a neutral zone. If now the temperature in the slab be allowed to become uniform throughout, thus regaining its original condition, the thermal gradient and hence the stresses will disappear. On the other hand, if the glass be cooled, there will be observed forces similar to those arising from heating, but opposite in sign; that is, tension on the outside and compression in the middle. In general, then, a temperature gradient established by heating will produce in the outer layers a longitudinal compression, and a gradient established by cooling will cause a longitudinal tension.[9] Similarly, if for any reason a temperature gradient exist in a slab free from stress,[10] the removal of the temperature gradient (as, for example, by maintaining the surface at a constant temperature) will cause

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[8] The block is assumed to be large enough so that the end effects may be neglected.

[9] In solids of other shapes the distribution of stress will be more complicated than in the slab. In a sphere, for example, which is being heated, there will be a radial tension all the way from centre to surface, a tangential compression in the outer layers, and a tangential tension in the central portion.

[10] *E.g.*, see below (December number), for the case for glass cooled at a constant rate from a high temperature.

stresses equal and opposite in sign to those which would be produced by the establishment of the same temperature gradient.

Temporary and Permanent Strain.—So much for the behavior of glass at temperatures not too high; that is, at temperatures such that the glass does not flow appreciably and thus acts like an elastic solid. At higher temperatures, however, the situation may be quite different. The glass may flow, and by internal displacements the stresses may gradually relieve themselves, the rate of release being dependent on the viscosity, which in turn decreases steadily as the temperature is raised. Consequently the stresses engendered in a block of glass by heating or cooling as described above may not be permanent; indeed, for temperatures at which the glass becomes a thin liquid the stresses may be so evanescent as to escape detection.

The stresses already discussed may be called *temporary,* since they continue only so long as the causative temperature gradient is maintained and tend to disappear even at low temperatures by removal of the temperature gradient. Let us now inquire how a block of glass may receive *permanent* stresses; that is, stresses which persist in glass even though it may be without thermal gradient. Consider a slab of ordinary plate glass at, say, 650° (a temperature at which stresses in this kind of glass disappear almost instantaneously), and suppose that its surface be allowed to cool at a uniform rate. As shown in a previous publication,[11] within a certain time after the commencement of uniform heating or cooling the temperature distribution will be practically parabolic and will remain constant so long as the time rate of temperature change remains constant. We will suppose then that the temperature gradient in the block of glass has reached a steady state while the glass is yet soft and thus unable to retain the temporary strains caused by the introduction of this gradient. The glass, therefore, will not be under stress while the temperature gradient is being established, nor, so long as it is being cooled at a uniform rate, will there be any stress developed, because the temperature differences in the transverse direction remain constant. But when the surface of the glass has arrived at the temperature of the surroundings (say, room temperature), we may suppose that it is cooled no further and that the temperature finally becomes uniform throughout the slab. The

[11] E. D. Williamson and L. H. Adams: *Phys. Rev.,* 14, 108 (1919).

removal of this temperature-gradient, as explained above, will cause stresses of the same kind as those produced by heating, and consisting therefore of longitudinal compression on the outside and tension on the inside. Strain caused by this system of stresses we shall call *ordinary* strain, since it is the usual kind of permanent strain, and strain introduced when a solid is beginning to cool we shall call *reverse* strain.

It thus appears that a block of glass cooled from a temperature at which it is soft to some other temperature at which it is hard, acquires at the lower temperature *ordinary*, *permanent* strain. Figure 1 indicates graphically how a slab of glass may receive strain by cooling from a high temperature. The dotted lines indicate strain and the full lines temperature distribution

Fig. 1.
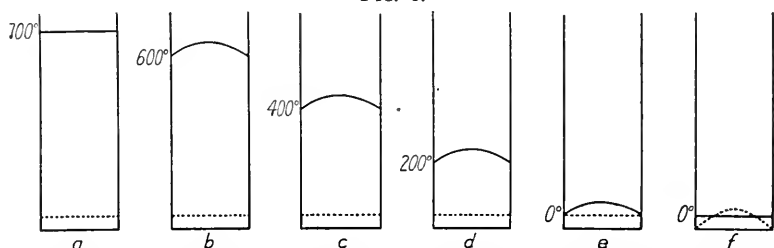
Diagram showing in several stages how a slab of glass cooled at a *uniform* rate from a sufficiently high temperature receives internal strain only when the cooling is stopped. The abscissæ represent distances in a direction normal to the surface, and the ordinates represent temperature (full lines) or strain (dotted lines).

in a direction normal to the faces of the slab, which in the figure is assumed to be 2 cm. thick and to be cooled at a rate of 10° C. per minute.

On the other hand, as shown in Fig. 2, glass at a temperature below that at which appreciable softening occurs, and initially without thermal gradient, will not acquire permanent strain when cooled to room temperature, the reverse strain introduced when the glass begins to cool being exactly balanced by the ordinary strain set up when the temperature gradient is ironed out at the lower temperature.

It is evident, therefore, that in dealing with the internal strains caused by the uniform cooling of glass we may consider two limiting cases: (1) cooling from a relatively high temperature with the production of permanent strain, and (2) cooling from a relatively low temperature, in which case no permanent strain is introduced.

Glass cooled from some intermediate temperature will acquire internal strain, the amount of which will lie between the amounts received in the two above-mentioned cases. Referring to Fig. 3, let the slab of glass initially at 500° throughout and free from stress be cooled as before at a rate of 10° C. per minute. Then,

FIG. 2.
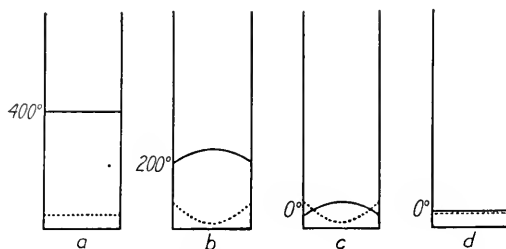
Similar to Fig. 1, except that the glass is cooled from a temperature below the annealing range, in which case no permanent strain is introduced.

just as in the previous case, a parabolic temperature gradient is soon established in the block, thereby causing a certain amount of reverse strain, but while the gradient is being established, or after the gradient has been established, part of this reverse strain will disappear by viscous yielding of the glass, and there-

FIG. 3.
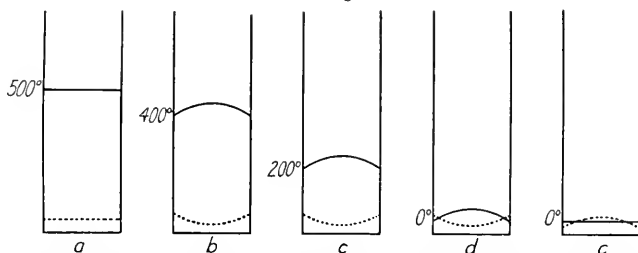
Similar to Fig. 1, except that the glass is cooled from a temperature within the annealing range. In this case strain is introduced, but less in amount than that shown in Fig. 1.

fore when the gradient is finally ironed out at room temperature the reverse strain will not be sufficient to neutralize the ordinary strain produced at the lower temperature. The residue is the strain finally observed.

Nature of the Problem.—Although the foregoing discussion has been limited to the special case of cooling at a uniform rate, a little consideration will show that the explanation given may

be extended to other kinds of cooling and that in general *the strain remaining in a block of glass is equal and opposite in sign to the reverse strain lost by viscous yielding in the early stages of the cooling process.*[12]   In its larger aspects, then, the formation and removal of strain in optical and other glasses may be treated as a purely mechanical process, and most of the questions involved in the annealing of glass may be answered without having recourse to matters concerning the state of aggregation or the molecular nature of the glass.   The problem of glass annealing may be resolved into two parts comprising: (1) a determination of the temporary stresses produced in a block of glass when heated or cooled in a given way, and (2) a measurement of the rate of release of stress at various temperatures.   Part one, involving first, a computation of the temperature distribution in glass on cooling, and second, a determination of the corresponding stresses, has been treated in previous publications from this Laboratory.[13] For part two, we have now obtained the requisite data, and in what follows we present the results of our measurements on the rate of release of stress, together with a description of the method and a discussion of the bearing of these results on the annealing of glass.

EXPERIMENTAL DETERMINATION OF RELEASE OF STRAIN.

Detection of Strain.—When a block of glass is subjected to a thrust it becomes doubly refracting, and when viewed in polarized light between crossed nicols it shows interference colors.   It was first proved by Brewster [14] that under thrust the block of glass behaves as a uniaxial optically negative crystal and that the bire-

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[12] Strain in quickly cooled glass is usually explained as follows: When the softened glass begins to cool, the outside hardens while the inside is yet soft; then as the cooling continues, the inside tends to shrink away from the hardened crust and the outer layers are brought into a state of thrust and the inner layers into a state of tension (compare Hovestadt, *op. cit.,* pp. 66, 67).   This explanation is not only incomplete but it is misleading.   It takes no account of the fact that a lump of soft glass under certain conditions may be rapidly cooled to a completely hardened state without any strain being introduced before, during, or after the hardening of the outer crust.   It takes no account of the fact that ordinarily a large part of the strain found in unannealed glass has arisen at comparatively low temperatures, far below the hardening range, and it ignores the existence of temporary stresses and of the dependence of stress upon direction.

[13] *Phys. Rev.,* **14,** 99–114 (1919).   *J. Wash. Acad.,* **9,** 209–217 (1919).

[14] Brewster: *Phil. Trans.,* 1814, 1815, 1816.

fringence is proportional to the intensity of the stress. The method commonly used for the detection and measurement of strain in glass utilizes this phenomenon. In actual practice light polarized by reflection or by means of a nicol prism is passed through the glass and then through a second nicol prism. As viewed between crossed nicols, unstressed glass remains dark, but stressed glass shows interference colors from which may be inferred the directions and amounts of the stresses. In order to see how this may be done, let us suppose that, as in Fig. 4, a block of glass is subjected to a thrust F in the direction OY and that a ray of light passes through the block in the direction OX.

FIG. 4.
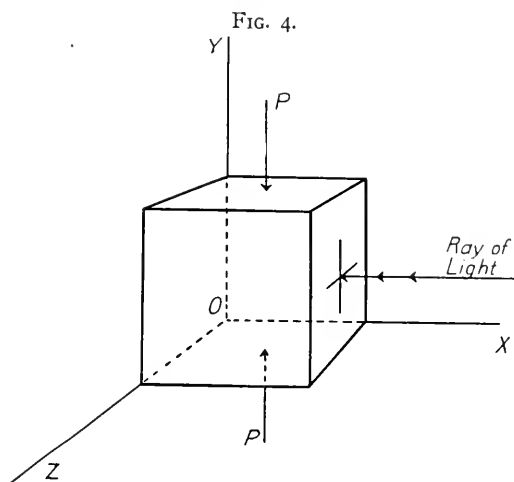
Diagram to accompany explanation in text of effect of strain in glass on a beam of polarized light.

The refractive indices n_y and n_z for light vibrating in the directions OY and OZ will in general differ from n, the refractive index in the unstressed medium. As shown previously,[15]

$$\frac{n_y - n}{n_y} = \frac{F}{E}\left(-2\sigma \, \frac{p}{v} + \frac{q}{v} \right) \tag{1}$$

and

$$\frac{n_z - n}{n_z} = \frac{F}{E}\left[(1 - \sigma) \, \frac{p}{v} - \sigma \frac{q}{v} \right] \tag{2}$$

[15] *J. Wash. Acad. Sci.*, **9**, 618 (1919).

It may also be noted that for a simple thrust or tension the stress F is related to the strain S by the relation

$$S = F/E$$

in which $\frac{p}{v}$ and $\frac{q}{v}$ are optical constants, E is Young's modulus of elasticity, and σ is Poisson's ratio.[16] Moreover, the birefringence,[17] $n_y - n_z$, is equal to a constant B times the thrust F, thus

$$n_y - n^2 = BF \tag{3}$$

in which

$$B = \frac{n}{2R}\left(\frac{q}{v} - \frac{p}{v}\right)$$

R being the rigidity.

In Table I the values of B for the glasses which we have investigated [18] are tabulated, along with other chemical and physical constants. The values of α, the coefficient of expansion, and κ, the thermal diffusivity, were calculated for the most part from data given by Hovestadt;[19] the remaining constants were copied from a former publication of the authors.[20]

The birefringence multiplied by the thickness of material traversed by the light is equal to the optical path difference δ; that is,

$$l(n_y - n_z) = l\,\triangle n = \delta \qquad \cdot \tag{4}$$

in other words, this quantity δ, which may be measured by standard methods,[21] is directly related to the birefringence, and hence, by

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[16] For the case of an initially isotropic material

$$E = \frac{9KR}{3K + R}, \text{ and } \sigma = \frac{3K - 2R}{6K + 2R}.$$

[17] Also commonly denoted by $n_\varepsilon - n_\omega$.

[18] Since publishing our measurements on the birefringence-stress ratio for various glasses, we have noticed the results of L. N. G. Filon, *Cambridge Phil. Soc., Proc.*, **11**, 478–492 (1900–1902); **12**, 55–64, 313–337 (1902–1904). Measurements were made at different wave-lengths. In order to compare his results with ours the values of B for wave-length $550\mu\mu$ are given below:

Glass	Per Cent PbO	B_{550}
Jena, O–152	16	2.72×10^{-7}
Jena, O–154	31	2.88×10^{-7}
Jena, O–103	47	2.83×10^{-7}
Jena, O–192	56	2.22×10^{-7}
Jena, O–41	63	1.74×10^{-7}
Jena, S–57	79	-1.05×10^{-7}
Plate glass	..	2.58×10^{-7}

[19] *Op. cit.*, pp. 147, 196, 210, 215.

[20] *J. Wash. Acad. Sci.*, **9**, 612, 613 (1919).

[21] See, for example, F. E. Wright: "The Methods of Petrographic Microscopic Research." Carnegie Institution of Washington, *Publ.* **158**, Chap. iii, 1911, or any text-book on optics.

TABLE I.

Chemical and Physical Constants of the Various Glasses.

Kind of glass	Chemical composition (approx.) wt. per cent.									Optical Properties			Mechanical Properties		Thermal Properties	
	PbO	CaO	BaO	ZnO	Na₂O	K₂O	Al₂O₃	B₂O₃	SiO₂	Refr. ind. n_D	Constringence ν	Birefringence due to 1 kg/cm² tension B	Modulus of compressibility Kg/cm² K	Modulus of rigidity Kg/cm² R	Coeff. of linear exp. α	Thermal diffusivity cm²/sec. κ
Borosilicate crown..	—	—	—	—	9	8	—	12	67	1.516	62	2.85×10^{-7}	0.43×10^{6}	0.29×10^{6}	7.5×10^{-6}	0.0045
Ordinary crown.....	—	12	—	—	14	1	—	—	73	1.523	59	2.57×10^{-7}	$.46 \times 10^{6}$	$.28 \times 10^{6}$	8.9×10^{-6}	.0047
Light barium crown.	—	—	29	11	3	5	1	4	47	1.574	57	2.81×10^{-7}	$.52 \times 10^{6}$	$.30 \times 10^{6}$	7.4×10^{-6}	.0039
Heavy barium crown	—	—	43	8	—	—	3	6	40	1.608	57	2.15×10^{-7}	$.53 \times 10^{6}$	$.29 \times 10^{6}$	6.4×10^{-6}	.0040
Barium flint........	24	—	15	8	3	4	—	—	46	1.606	44	3.10×10^{-7}	$.42 \times 10^{6}$	$.26 \times 10^{6}$	7.7×10^{-6}	.0038
Light flint.........	35	—	—	—	6	5	—	—	54	1.573	42	3.13×10^{-7}	$.35 \times 10^{6}$	$.24 \times 10^{6}$	8.4×10^{-6}	.0040
Medium flint.......	48	—	—	—	3	4	—	—	45	1.616	37	2.67×10^{-7}	$.34 \times 10^{6}$	$.22 \times 10^{6}$	8.1×10^{-6}	.0038
Heavy flint........	52	—	—	—	3	3	—	—	42	1.655	33	1.22×10^{-7}	$.34 \times 10^{6}$	$.22 \times 10^{6}$	8.2×10^{-6}	.0036
Extra heavy flint...	69	—	—	—	—	3	—	—	28	1.756	27		$.32 \times 10^{6}$	$.20 \times 10^{6}$	8.5×10^{-6}	.0033

equation (3), to the stress in the glass. In the actual measurement of strain in glass the sample is placed between crossed nicols and, for maximum brightness of interference colors, is so placed that one of the principal directions of the piece is at an angle of 45° to the vibration direction of the polarized light. In measuring the optical path difference, the interference color observed may be compared with a Newton color scale [22] and the path difference thus estimated, or the path difference may be read directly on a graduated quartz wedge (of the type used in the petrographic microscope) placed between analyzer and polarizer. We have made use of the second method, except for some preliminary measurements, but the first is the more useful for the routine testing of glass. One division on the wedge was equivalent to $10\mu\mu$ and readings could easily be made to one-half division or $5\mu\mu$.

The sign of the path-difference may also be determined, and, since for most glasses $n_y - n_z$ is negative in the case of a thrust, it is evident that having determined for any part of a strained block of glass the direction of α, the lesser index, and of γ, the greater index, we know that in the given part of the block there is either a tension parallel to γ or a thrust parallel to α, or both tension and thrust in the stated directions. A sensitive-tint plate on which the α and γ directions are marked may be used for this purpose. For a series of glasses of increasing lead content $n_y - n_z$ diminishes and finally changes sign at about 74 per cent. PbO. For a glass of this composition the ordinary method for the measurement of strain would fail; stressed and unstressed glass would present the same appearance when viewed in polarized light. But fortunately glass containing as much as 74 per cent. PbO is very unusual and is rarely encountered by the maker or user of glass.

Description of Apparatus.—Figure 5 is a diagrammatic representation of the apparatus used for measuring the rate of release of stress at various temperatures. In the electric muffle furnace F was placed a slab of glass B, which was placed with its shortest dimension vertical, and was supported at three points. One of the three supports was adjustable from the outside so that the

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[22] Such charts may be found in J. P. Iddings' " Rock Minerals " (1911), and H. M. Winchell's " Optical Mineralogy " (1909).

A sensitive-tint plate, consisting of a plate of selenite (or other suitable material) having a path difference of about $570\mu\mu$ is a common and important adjunct, especially for the estimation of a small amount of strain.

slab could be leveled and brought into line with the two circular openings, one in either end of the furnace. In these openings were fitted alundum tubes H, H (respectively 1.5 and 2.5 cm. in diameter), the object of which was to reduce convection currents between the cold air outside the furnace and the hot air inside. One side of the furnace chamber was closed by a door of refractory material.

Light from a lamp was diffused by the ground-glass screen G and polarized by reflection at a glass plate.[23] From the polarizer the light passed into the furnace, through the glass B and out through the tube H. The remainder of the optical system

FIG. 5.
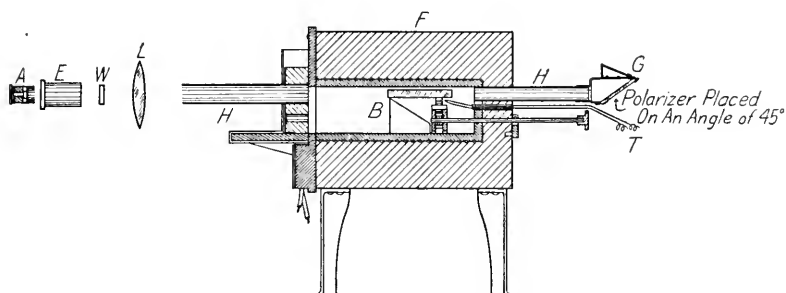
Apparatus used for measurements of rate of release of stress in various glasses at various constant temperatures. F is an electric muffle furnace in which is supported the glass slab B. Light from a lamp is diffused by the ground glass screen G, is then polarized by reflection from a glass plate and passes successively through the slab B, the lens L, the wedge W (seen end on in the figure), the eyepiece E and the analyzing nicol A. Temperature is measured by the thermocouple T in conjunction with a potentiometer.

consisted of a lens L, a quartz wedge W placed horizontally, an eyepiece E which was focussed on W, and finally the analyzer, a cap nicol A. The wedge W was so graduated that one division corresponded to $10\mu\mu$ optical path difference.[24] The analyzer and polarizer were crossed and the angle between the horizontal and the plane of polarization was $45°$.

The appearance of the field of view as seen by the eye placed at A, is suggested by Fig. 6. At a is shown the field of view when the glass is unstrained, the vertical black line of zero path difference is straight and coincident with the zero of the scale.

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[23] For maximum polarization the angle of incidence is $\tan^{-1}n$. Taking n as 1.51, the angle is therefore $66.5°$. Either black glass or ordinary glass blackened on the back may be used.

[24] A $\mu\mu$ is a millimicron or 10^{-7} cm.

The presence of internal strain is indicated by a curvature of the black line the position of which, with reference to the scale, shows the transverse distribution of strain.   Thus in Fig. 6b the path difference through the middle of the slab is $170\mu\mu$, at the surface is much greater but of opposite sign, while at a little more than half the distance from centre to surface it is zero.[25]

Temperature was measured with the usual equipment consisting of a platinum-platinrhodium thermocouple T, and a potentiometer (not shown in the figure) reading to 1 microvolt.   The

Fig. 6.

a

b
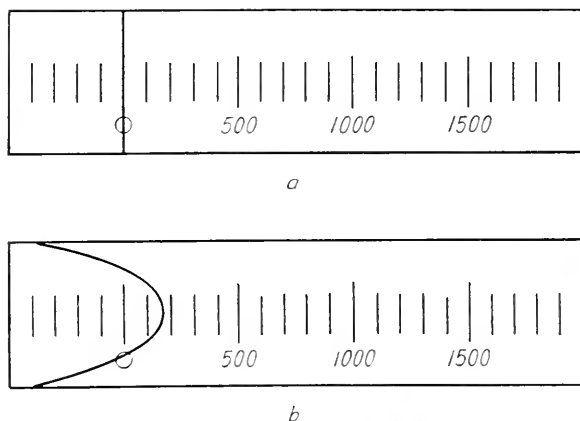
This diagram suggests the appearance of the graduated wedge as seen through the eyepiece and analyzer (see Fig. 5).   When the glass is unstrained (as at a) the black line is straight and coincident with the zero of the scale; but the presence of strain causes the line to become curved (as in Fig. 6b), and its position shows the distribution of strain throughout the block of glass. In the wedge actually used the divisions as shown in this figure were further subdivided so that 1 division equals $10\mu\mu$ path difference.

thermocouple junction was about 5 mm. below the lower surface of the glass.   The temperature corresponding to 1 microvolt is about $0.1°$, an unnecessarily high degree of precision for this work, but the greater sensitivity increases the ease of manipulation in maintaining a constant temperature by hand regulation. Time intervals were measured with an ordinary watch.

Method of Experiment.—In determining the rate of release of strain at constant temperature any one position in the slab may be chosen and successive observations of path difference at

[25] The curve of strain caused by heating or cooling at a constant rate is a parabola crossing the zero line at a distance from the centre equal to 0.578 of the semi-thickness.   Cf. *J. Wash. Acad. Sci.*, 9, 216 (1919), and equation (54) below.

that position may be made.   For the sake of convenience the
middle was selected and only the position of the apex of the curve
(Fig. 6b) was read.   The complex end-effects at either side of a
strained block of glass (as shown in Fig. 7a, b, and c) are far out-
side the field of view, and do not lead to any difficulties.   It may be
noted in this connection that for quantitative measurements a
cylinder is not so convenient as a slab.   If an unannealed glass
cylinder be viewed along its axis, the path difference is zero at
the centre and reaches its maximum value at the surface.   There-
fore, with a cylinder viewed lengthwise, the readings must be
taken at some portion of the curve other than the apex; while with
a slab one can take advantage of the convenience of being able to
make the measurements at the apex of the curve.

FIG. 7.

a   b   c
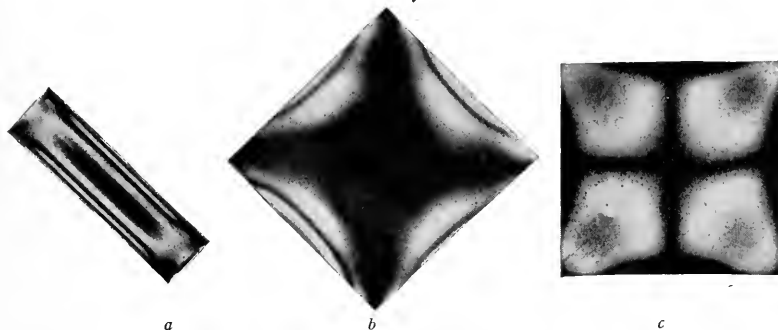
Three photographs showing the appearance of a slab of strained glass when viewed in polar-
ized light between crossed nicols.   a shows the glass viewed through the ends; and b and c
when viewed in the transverse direction.   In each case the planes of polarization are parallel
to the margins of the page.

The specimens of glass used were about 2 cm. in thickness and
8 cm. in length and breadth.   Two opposite edges were polished
and approximately plane parallel.   Since the presence of striæ
causes a distortion of the interference image, the best pieces were
selected from a large quantity of glass.

The slab of glass having been placed in position was leveled
and brought into line with the circular opening of the furnace.
The thermocouple junction was then adjusted and the door
closed.   The first stage of the experiment consisted in getting
strain into the glass.   This was accomplished by raising the tem-
perature about 50° above the temperature at which strain dis-
appears almost instantaneously (see below) and then dropping
the temperature rapidly by cutting off the current and opening the

door. When the temperature had fallen about 300° the current was turned on and the furnace brought up to the temperature at which the observations were to be made.

After this temperature had been reached, at least 20 minutes was allowed for the glass to attain a constant temperature throughout. The rate of release of stress at constant temperature was then determined by successive observations of path difference. The interval of time between readings depended on the rapidity with which the stress was released, so that at the higher temperature readings were taken a few minutes apart, while at lower temperatures several hours might elapse between two successive observations.

As a rule when the path difference had fallen to about 50$\mu\mu$ (5 or 6$\mu\mu$ per cm.) the series of measurements was considered complete, and after straining the block again, observations were made at some other temperature. Since the rate of release of strain increases very rapidly as the temperature is raised, the temperature-range over which it is convenient to make measurements is very short. Unless more than a working day is allowed for one series, this range is less than 50°. At temperatures much above this range nearly all the strain will have vanished before uniformity of temperature is attained, and at lower temperatures not enough of the strain will have been released in less than one day. For one kind of glass (medium flint) the temperature range was extended at the lower end by observing the strain remaining in the block of glass after immersion for several weeks in the vapor from boiling benzophenone (b.p. 306°). During this time the glass was taken out at intervals of a week or more, and after a measurement of the strain the glass was replaced in the benzophenone bath.

Experimental Results.—In Table II are collected the results of the several series of measurements obtained for each of the eight types of glass as defined by the properties already given in Table I. With each set of observations is shown the temperature, θ, the elapsed times, t, in minutes, and the corresponding values of δ, the optical path difference in $\mu\mu$. Each value for δ is the mean of two or more separate readings, usually by two independent observers. The method of obtaining the calculated values of δ (in the third column) and the significance of the factor A' appearing at the top of each section of the table, will be discussed further on in the paper.

TABLE II.

Experimental Results. Measurements of Release of Stress at Constant Temperature.

Time	Path. diff., δ	δ, calc. by equation 7b.	Time	Path diff., δ	δ, calc. by equation 7b.
Borosilicate Crown $\theta = 480°$ $A' = .0000072$			Ordinary Crown* $\theta = 500°$, $A' = .000105$		
0 min.	$284\mu\mu$	$280\mu\mu$	0 min.	$120\mu\mu$	$123\mu\mu$
69	240	246	60	75	69
157	209	213	120	50	48
214	200	196	240	20	30
Borosilicate Crown $\theta = 500°$, $A' = .000022$			Ordinary Crown $\theta = 515°$, $A' = .00040$		
0 min.	$462\mu\mu$	$455\mu\mu$	0 min.	$208\mu\mu$	$195\mu\mu$
31	338	347	5	133	140
76	252	258	10	113	109
149	170	182	20	88	76
209	153	147	50	(25)	(40)
314	118	110			
Borosilicate Crown $\theta = 530°$, $A' = .00021$			Light Barium Crown $\theta = 500°$, $A' = .0000113$		
0 min.	$236\mu\mu$	$243\mu\mu$	0 min.	$732\mu\mu$	$719\mu\mu$
22	122	115	12	646	656
44	73	75	33	547	567
98	33	41	64	436	473
156	24	27	143	325	333
			230	256	251
Ordinary Crown* $\theta = 450°$, $A' = .0000034$			342	215	190
0 min.	$510\mu\mu$	$500\mu\mu$	Light Barium Crown $\theta = 516°$, $A' = .000028$		
60	440	454			
120	410	415	0 min.	$396\mu\mu$	$400\mu\mu$
240	370	355	31	288	297
420	310	292	49	272	258
720	220	225	94	202	195
1080	160	176	141	157	155
1725	120	127	177	125	134
Ordinary Crown* $\theta = 470°$, $A' = .000024$			Light Barium Crown $\theta = 540°$, $A' = .00020$		
0 min.	$315\mu\mu$	$312\mu\mu$	0 min.	$162\mu\mu$	$(162)\mu\mu$
60	210	215	29	83	(83)
120	175	164	Heavy Barium Crown $\theta = 540°$, $A' = .0000062$		
240	110	111			
420	80	75	0 min.	$668\mu\mu$	$658\mu\mu$
Ordinary Crown* $\theta = 490°$, $A' = .000049$			25	586	594
			62	511	522
0 min.	$230\mu\mu$	$230\mu\mu$	88	464	482
60	130	137	129	416	429
120	100	98	175	379	382
180	85	76	284	309	304

Table II.—*Continued.*

Experimental Results. Measurements of Release of Stress at Constant Temperature.

Time	Path. diff., δ	δ calc. by equation 7b.	Time	Path. diff., δ	δ, calc. by equation 7b.
Heavy Barium Crown			**Light Flint; θ = 385°, A' = .000080—con.**		
θ = 565°, A' = .000034			48	155	158
			72	118	121
0 min.	470μμ	483μμ	100	100	95
18	364	373	140	80	73
52	268	260			
78	216	212	**Light Flint**		
123	160	160	θ = 400°, A' = .00017		
151	134	139			
213	104	107	0 min.	280μμ	289μμ
			10	195	194
Heavy Barium Crown			26	135	127
θ = 590°, A' = .00047			44	97	91
			60	72	73
0 min.	149μμ	152μμ	90	47	53
18	72	67	139	27	37
40	36	39			
66	26	27	**Light Flint**		
91	18	20	θ = 415°, A' = .00046		
Barium Flint			0 min.	293μμ	299μμ
θ = 450°, A' = .000022			5	185	177
			10	130	126
0 min.	492μμ	493μμ	20	80	80
25	386	387	28	58	62
60	300	299	40	40	46
103	229	233			
193	158	159	**Medium Flint**		
294	116	118	θ = 306°, A' = .000000102		
360	100	100			
			0 min.	356μμ	351μμ
Barium Flint			16020	205	223
θ = 470°, A' = .00013			28980	170	173
			60240	130	112
0 min.	312μμ	324μμ			
55	108	98	**Medium Flint**		
91	59	67	θ = 374°, A' = .0000106		
134	39	49			
			0 min.	594μμ	578μμ
Barium Flint			32	465	483
θ = 490°, A' = .00031			57	409	428
			92	349	370
0 min.	155μμ	156μμ	181	261	274
11	107	102	270	228	218
22	70	76	365	192	182
33	56	60			
58	45	41	**Medium Flint**		
			θ = 390°, A' = .000040		
Light Flint					
θ = 385°, A' = .000080			0 min.	573μμ	568μμ
			20	378	391
0 min.	415μμ	400μμ	55	253	253
11	280	296	85	190	194
22	223	235	120	160	153
34	188	192	140	130	136

TABLE II.—*Continued*.

Experimental Results.　Measurements of Release of Stress at Constant Temperature.

Time	Path diff., δ	δ, calc. by equation, 7b.	Time	Path diff., δ	δ, calc. by equation 7b.
Medium Flint $\theta = 406°$, $A' = .00017$			Heavy Flint $\theta = 400°$, $A' = .00025$		
o min.	350μμ	345μμ	o min.	145μμ	147μμ
10	205	217	15	100	95
20	160	159	19	90	87
40	103	103	27	70	74
60	80	76	58	50	47
90	52	55	89	30	34
			168	19	20
Heavy Flint $\theta = 375°$, $A' = .000029$			Extra Heavy Flint $\theta = 350°$, $A' = .000046$		
o min.	230μμ	225μμ			
18	198	201	o min.	134μμ	130μμ
62	153	159	13	120	121
133	119	120	90	81	86
178	109	104	156	69	69
			259	54	53
			330	46	46
Heavy Flint* $\theta = 385°$, $A' = .000075$			Extra Heavy Flint $\theta = 370°$, $A' = .00021$		
o min.	205μμ	207μμ			
31	135	140	o min.	108μμ	108μμ
60	115	107	29	65	65
122	72	71	59	43	46
166	47	58	98	37	35

The portions of the table marked with an asterisk (*) represent preliminary measurements which were made by the color-comparison method mentioned above.　Except for some other preliminary observations the only measurements omitted from Table II were two series with ordinary crown glass which were obviously affected by an error in temperature.

Representation of Results.—It has generally been supposed that internal stress in a viscous substance is relieved at a rate which is proportional to the stress.　If this were the case we could write

$$- \frac{dF}{dt} = const \cdot \times F = mF$$

in which t denotes the time, F the force or stress.　Integrating this equation and applying the initial condition that when $t = o$, $F = F_o$, we have either

$$\frac{F}{F_o} = e^{-mt} \qquad (4a)$$

or

$$\log F + m't = const. \qquad (4b)$$

That is, the stress F would decrease exponentially with respect to time, and by plotting (for example, on semi-logarithm paper) log F against t for any series of observations, we would expect to obtain a straight line. Unfortunately, however, this expectation was not realized. In Fig. 8 two typical sets of measurements are plotted with log F as ordinate and t as abscissa. The smooth curve passing through the points is always convex toward the t-axis and deviates by more than the experimental error from any

Fig. 8.
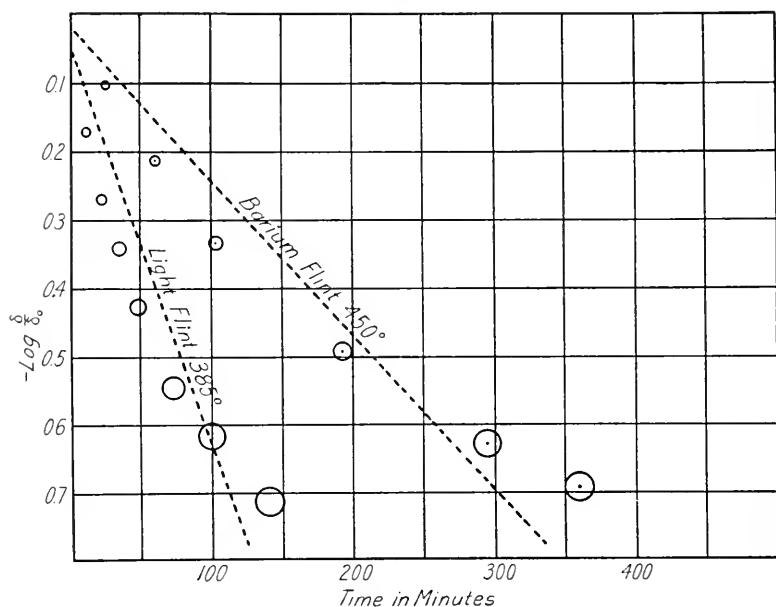
Graphs showing for two typical cases log $\frac{\delta}{\delta_{0}}$ plotted as ordinate against t, the time in minutes, as abscissa. The points do not lie in a straight line as would be the case if the release of stress proceeded according to Maxwell's relation. The radii of the circles representing the observations correspond in magnitude to an error of $5\mu\mu$.

straight line which can be drawn. It is evident, therefore, that the rate of diminution of F is not proportional to F. In the later stages the stress falls off more slowly than would be expected from its initial rate. Consequently we must seek some other law to represent the experimental results. In this connection it is interesting to note the remarks of Clerk Maxwell, in 1866, concerning the release of internal strain.[26]   He wrote:

[26] Clerk Maxwell: Collected Papers. Vol. 2, p. 30. Univ. Press, Cambridge, 1890. See also *Phil. Trans.*, 157.

" * * * The phenomena of viscosity in all bodies may be described, independently of hypothesis, as follows:

" A distortion or strain of some kind, which we may call S, is produced in the body by displacement. A state of stress or elastic force which we may call F is thus excited. The relation between the stress and the strain may be written $F = ES$, where E is the coefficient of elasticity for that particular kind of strain. In a solid body free from viscosity, F will remain $= ES$, and

$$\frac{\mathrm{d}F}{\mathrm{d}t} = E \frac{\mathrm{d}S}{\mathrm{d}t}.$$

If, however, the body is viscous, F will not remain constant, but will tend to disappear at a rate depending on the value of F, and on the nature of the body. *If we suppose this rate proportional* [27] *to F,* the equation may be written

$$\frac{\mathrm{d}F}{\mathrm{d}t} = E \frac{\mathrm{d}S}{\mathrm{d}t} - \frac{F}{T},$$

which will indicate the actual phenomena in an empirical manner. For if S be constant,

$$F = ESe^{-\frac{t}{T}}$$

shewing that F gradually disappears, so that if the body is left to itself it gradually loses any internal stress, and the pressures are finally distributed as in a fluid at rest.

" If $\frac{\mathrm{d}S}{\mathrm{d}t}$ is constant,[28] that is, if there is a steady motion of the body which continually increases the displacement,

$$F = ET \frac{\mathrm{d}S}{\mathrm{d}t} + Ce^{-\frac{t}{T}}$$

shewing that F tends to a constant value depending on the rate of displacement. The quantity ET, by which the rate of displacement must be multiplied to get the force, may be called the coefficient of viscosity. It is the product of a coefficient of elasticity, E, and a time T, which may be called the ' time of relaxa-

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[27] The italics are ours.

[28] We may also consider the condition for F constant, which leads to the equation:

$$E \frac{\mathrm{d}S}{\mathrm{d}t} = \frac{F}{T}.$$

For large values of t this becomes identical with the equation for $\frac{\mathrm{d}S}{\mathrm{d}t} = const.$

tion ' of the elastic force.   In mobile fluids T is a very small fraction of a second, and E is not easily determined experimentally. In viscous solids T may be several hours or days, and then E is easily measured.   It is possible that in some bodies T may be a function of F *   *   *."

Maxwell was thus fully aware of the possibility that his assumption as to the proportionality of $\frac{dF}{dt}$ to F might not be justified in all cases.   Our results clearly indicate that with glass, at any rate, the release of stress at constant temperature does not proceed according to the simple law expressed by equation (4), and consequently we must seek some other law to represent the experimental results.

Since the stress decreases less rapidly for small amounts of stress than would correspond to equation (4), it was thought that $\log F$ might be proportioned to some power of t other than the first power.   Accordingly the equation

$$\log \cdot \frac{F_o}{F} = mt^b \qquad (5)$$

was tried.   The values of the constants m and b were obtained graphically by plotting $\log \log \frac{S_o}{S}$ against $\log t$ and drawing the best straight line through the points.   This formula was found to represent the results satisfactorily, the deviations on the whole being no greater than the experimental error.   The values of b, the power of t, varied between 0.5 and 0.7 for the different sets of observations.

Michelson [29] states that the behavior of any solid under stress may be considered as the resultant of the four separate effects: the elastic displacement, the elastico-viscous displacement, the viscous displacement, and the lost motion.   The elastico-viscous displacement is represented by the formula $S_2 = A_2 \left(1 - e^{-\alpha \sqrt{t}}\right)$, or, rearranging the symbols, by

$$\log \frac{S_o}{S} = a\, t^{\frac{1}{2}},$$

which closely resembles our equation when $m = \alpha$ and $b = \frac{1}{2}$.

But although equation (5) satisfactorily represents the data, it is inconvenient for calculation and especially for extrapolation.

[29] A. A. Michelson: *Proc. Nat. Acad. Sci.,* **3,** 319–323 (1917).   *J. Geol.,* **25,** 405–410 (1917); **28,** 18–24 (1920).

A much better formula was derived from the arbitrary assumption
that the rate of release of stress is proportional to the square of
the stress; that is,

$$- \frac{dF}{dt} = ABF^2 \qquad\qquad (6)$$

which by integration yields the rectangular hyperbola :

$$\frac{1}{F} - \frac{1}{F_0} = ABt \qquad\qquad (7a)$$

in which F_0 is the stress at the time $t = 0$, and the product AB
may be considered as one constant. The quantity directly meas-
ured is not F but δ, the optical path difference. To put the equa-
tion in convenient form for calculation, $F = \delta/Bl$ (see equations 3
and 4) is substituted in the above expression, yielding,

$$\frac{1}{\delta} - \frac{1}{\delta_0} = A't \qquad\qquad (7b)$$

A' being the equivalent of A/l. Although this equation contains
one constant less than equation (5), it represents the experi-
mental results fully as well. It is also more convenient for calcu-
lation. Hence, without making any attempt to give a physical
interpretation to this empirical relation, we have used it for inter-
polating and extrapolating our results. In Table II are included
the values A', for the several series of measurements, and also
the values of δ, calculated by equation (7b). It is evident that
the agreement between δ " observed " and δ " calculated " is, on
an average, within about $5\mu\mu$, and it follows, therefore, that the
above formula represents with satisfactory precision the release
of stress in glass—at any rate, for the temperatures and with the
amounts of stress with which it is convenient to measure the speed
of annealing. Fig. 9, in which $\frac{1}{\delta}$ in $\mu\mu$ is plotted against t in min-
utes, shows graphically the order of agreement for three cases
already plotted in a different way in Fig. 8.

The values of A' for the various kinds of glass and for the
various temperatures are collected in Table III. In the second
column is tabulated l, the length of the slab in the line of sight,
and in the third column [30] is A (the product of A' and l). The quan-

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[30] For the computations involving A and A', t is in minutes, δ in $\mu\mu$ and
Δn in $\mu\mu$ per cm.; that is, 10^7 times the difference in refractive indices.

tity A is a measure of the rate at which the stress, F, is released when the temperatures remain unchanged. A is also related to the fluidity or mobility; that is, to the reciprocal of the viscosity. Sometimes it is more convenient to describe the stress in terms of birefringence (*i.e.*, path difference per unit length). Substituting $\frac{\triangle n}{B}$ for F in equation (7a), we have

$$\frac{1}{\triangle n} - \frac{1}{(\triangle n)_0} = At \qquad (7c)$$

Fig. 9.
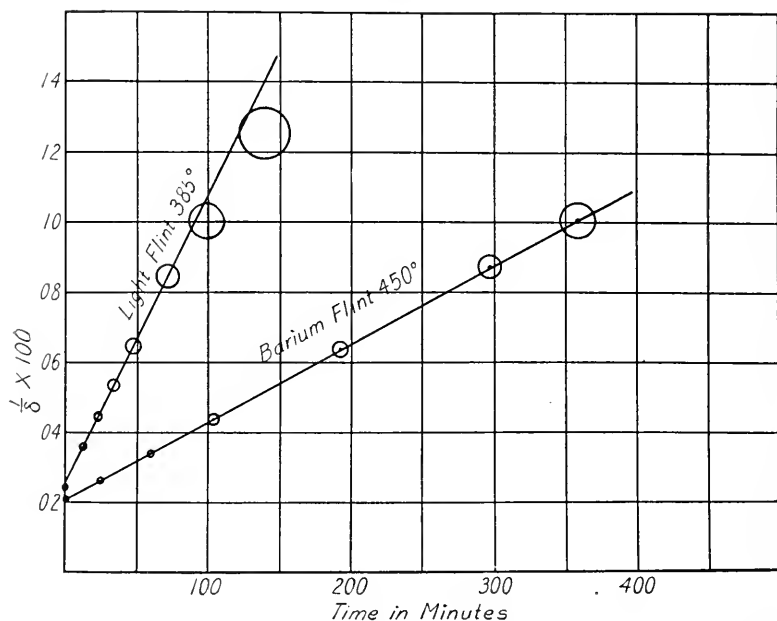
The same observations as those plotted in Fig. 8 are here plotted with $\frac{1}{\delta}$ as ordinate and t (the time) as abscissa. In this case the circles representing the observations lie, within the error of experiment, on a straight line. Here, as in Fig. 8, the radii of the circles indicate the shift in position due to an error of $5\mu\mu$.

The quantity A indicates (in optical rather than mechanical units) the variation of stress with time; it may therefore be called the annealing constant of the particular glass and at the temperature in question. Unlike A', this quantity is independent of the length of the glass specimen. On the other hand, if the law of release of stress happened to follow equation (4), the analogous equa-

tions containing F, δ or Δn would contain identical constants, *i.e.*, in that case, one and the same constant would determine the rate of disappearance of stress, or path difference, or birefringence.

TABLE III.

The Values of the Annealing Constant A for the Various Glasses at Various Temperatures.

Kind of glass	Temperature degrees C θ	Constant of equation 7b A'	Length of slab l	Annealing constant A $(= A' \times l)$
Borosilicate crown........	480	.0000072	7.5 cm.	.000054
Borosilicate crown........	500	.000022	7.5 cm.	.00017
Borosilicate crown........	530	.00021	7.5 cm.	.0016
Ordinary crown..........	450	.0000034	10.8 cm.	.000037
Ordinary crown..........	470	.000024	10.8 cm.	.00026
Ordinary crown..........	490	.000049	10.8 cm.	.00053
Ordinary crown..........	500	.000105	10.8 cm.	.00113
Ordinary crown..........	515	.00040	10.8 cm.	.0043
Light barium crown......	500	.0000113	7.5 cm.	.000085
Light barium crown......	516	.000028	7.5 cm.	.00021
Light barium crown......	540	.00020	7.5 cm.	.0015
Heavy barium crown.....	540	.0000062	7.5 cm.	.000047
Heavy barium crown.....	565	.000034	7.5 cm.	.00026
Heavy barium crown.....	590	.00047	7.5 cm.	.0035
Barium flint.............	450	.000022	7.5 cm.	.00017
Barium flint.............	470	.00013	7.5 cm.	.00098
Barium flint.............	490	.00031	7.5 cm.	.0023
Light flint..............	385	.000080	10.0 cm.	.00080
Light flint..............	400	.00017	10.0 cm.	.0017
Light flint..............	415	.00046	10.0 cm.	.0046
Medium flint...........	306	.000000102	7.5 cm.	.00000077
Medium flint...........	374	.0000106	7.5 cm.	.000080
Medium flint...........	390	.000040	7.5 cm.	.00030
Medium flint...........	406	.00017	7.5 cm.	.0013
Heavy flint.............	375	.000029	7.5 cm.	.00022
Heavy flint.............	385	.000075	7.5 cm.	.00056
Heavy flint.............	400	.00025	7.5 cm.	.0019
Extra heavy flint	350	.000046	7.5 cm.	.00034
Extra heavy flint	370	.00021	7.5 cm.	.0016

Although, as stated above, our results are satisfactorily represented by equation (7b), the fact was not disregarded that this is only an empirical equation, and like any other empirical equation, is not to be relied upon for expressing the behavior of glass at temperatures far removed from those at which the measurements were made. In order to determine the character of the agreement at much lower temperatures, a set of readings were taken with the light flint glass at about 300°, which is 85° below the lowest temperature at which the previous measurements were made. The glass anneals very slowly at this temperature, and

after three weeks nearly half of the original strain remained. The results are shown in Table IV and in Fig. 10. Unfortunately, the curve representing the points where $\frac{1}{\delta}$ is plotted against t

TABLE IV.

Special Experiment with Light Flint Glass at 300°—a Temperature at which the Release of Intense Stresses Proceeds very Slowly.

Time of reading	Elapsed time in minutes t	Optical path difference along middle δ	Temperature, degrees C
April 6, 2 P.M.	0	672	300.8
April 6, 4.30 P.M.	150	630	300.1
April 7, 10 A.M.	1200	555	298.7
April 7, 4.30 P.M.	1590	520	299.7
April 8, 10 A.M.	2640	478	299.5
April 8, 4.30 P.M.	3030	470	300.3
April 9, 11.15 A.M.	4155	445	300.1
April 10, 11.05 A.M.	5585	428	299.6
April 10, 4.30 P.M.	5910	420	300.2
April 11, 11.30 A.M.	7050	400	297.6
April 12, 9.30 A.M.	8370	385	299.1
April 13, 9.45 A.M.	9825	363	301.7
April 14, 10.30 A.M.	11310	350	300.0
April 15, 11.00 A.M.	12780	345	300.1
April 16, 4.30 P.M.	14550	333	299.9
April 19, 2.00 P.M.	18720	305	300.8
April 22, 9.40 A.M.	22780	297	301.0
April 27, 4.00 P.M.	30360	265	300.1

FIG. 10.
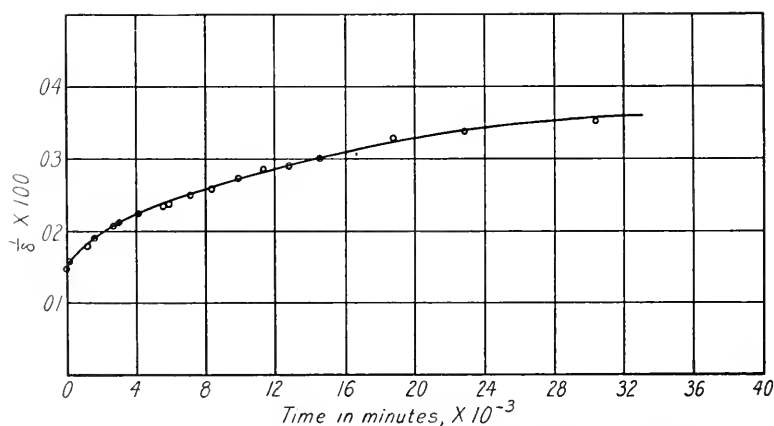
Graphical representation of data of special experiment with light flint glass at 300°. In this exceptional case (very low temperature and very slow release of stress) the graph of $\frac{1}{\delta}$ against t shows, particularly at the beginning, a considerable amount of curvature.

does not, in this case, prove to be a straight line, but is much curved at the beginning. This may be attributed, in large measure, to the circumstance that, whereas at higher temperatures a large amount of the initial strain is lost before the temperature is sufficiently constant for readings to be taken, at very low temperatures, on the other hand, the first reading is very nearly equal to the original strain. In this experiment, moreover, the initial strain happened to be somewhat higher than it was in the preced-

Fig. 11
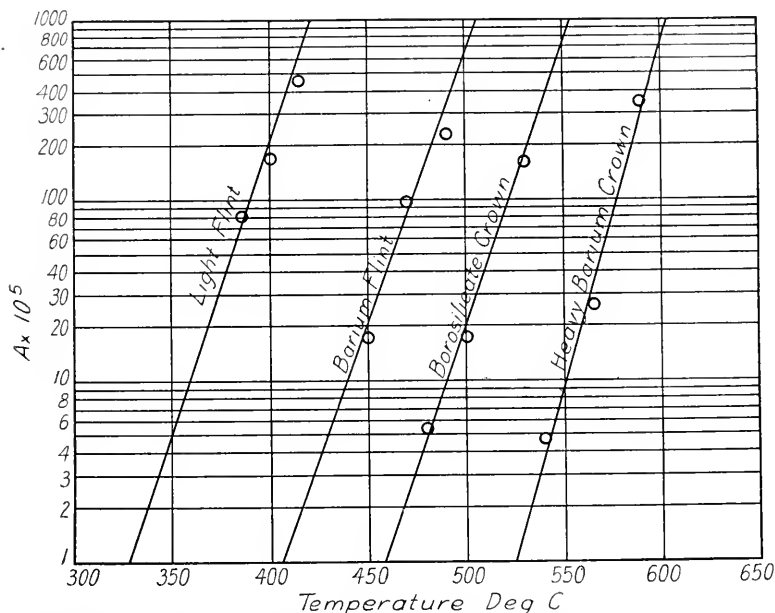
Showing the variation of the annealing rate, A, with temperature. The logarithm of A, as ordinate, is plotted against the temperature as abscissa. The observations are well represented by straight lines.

ing experiments. The fact that the temperature, as shown in Table IV, was not quite constant, probably does not vitally affect the character of the curve.

We must conclude, therefore, that at very low temperatures and for the initial part of the release of internal stress, formula (7) fails to represent the relation between stress and time. Nevertheless, we believe that within the temperature range, which is of the greatest practical importance, and except for the first part of the stress to be relieved, the above-mentioned formula gives

a useful and sufficiently accurate representation of the facts. At any rate, in the absence of a more satisfactory equation it will be convenient to use it, as shown below, in connection with the problems of glass-annealing.

We shall next consider the dependence of the annealing-constant upon the temperature. Twyman [31] has stated that the mobility of glass is a simple exponential function of the temperature. Our results confirm this conclusion, so that throughout the range

FIG. 12.
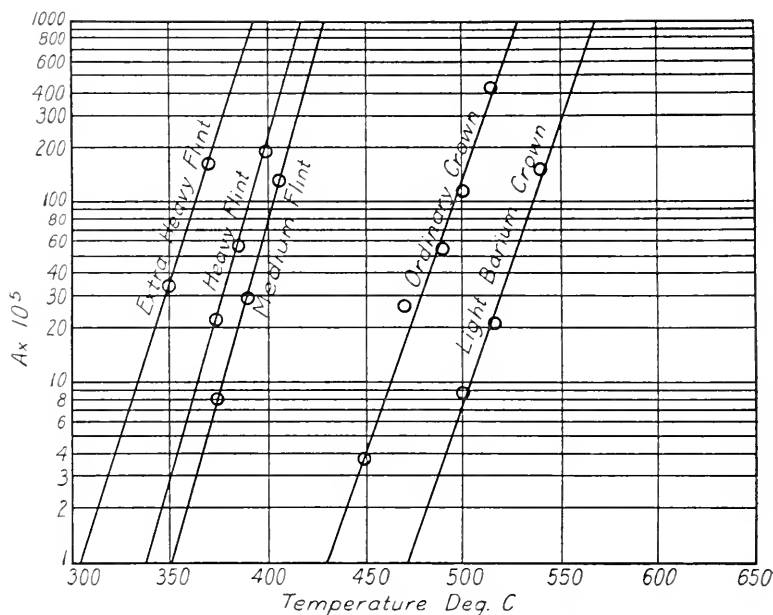
Similar to Fig. 11, but for the remaining five glasses.

of temperature covered by our experiments the variation of the annealing constant with the temperature is expressed by the equation

$$\log A = M_1 \theta - M_2 \tag{8}$$

M_1 and M_2 are (positive) constants. In Figs. 11 and 12, $\log A$ is plotted against θ (which, contrary to the usual convention, represents centigrade, not absolute, temperature). The points for any

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[31] F. Twyman: "The Annealing of Glass." *J. Soc. Glass Techn.*, **1**, 62 (1917).

one glass, as a rule, lie on a straight line from the position of which the constants M_1 and M_2 may be determined.

When M_1 and M_2 are known for each type of glass it is possible to calculate by equations (7) and (8) the time required at any temperature to reduce the stress in any glass from any initial to any final value. In other words, the annealing time under any prescribed conditions can be readily computed from two or more observations for each kind of glass at each of two or more temperatures. In Table V are assembled the values of M_1 and M_2 for the nine kinds of glass investigated. This table also shows the temperatures at which a given amount of stress would be

TABLE V.

Constants M_1 and M_2 of Equation (8), and Calculated Annealing-Temperatures for Various Annealing Times (when Birefringence along Middle of Slab is to be Reduced from $50\mu\mu$ to $2.5\mu\mu$ per cm.).

Kind of glass	M_1	M_2	Annealing temperatures, deg. C.						
			2 min.	10 min.	1 hr.	5 hrs.	1 day	1 wk.	1 mo.
Borosilicate crown	0.030	18.68	599	575	549	526	503	475	454
Ordinary crown..	.029	17.35	573	549	522	498	475	446	424
Light barium crown.........	.032	20.10	606	584	559	538	516	490	470
Heavy barium crown.........	.038	24.95	638	619	599	580	563	540	524
Barium flint.....	.028	16.28	556	531	503	478	454	424	401
Light flint.......	.033	15.92	461	439	416	395	374	348	329
Medium flint....	.038	18.34	464	445	425	407	389	366	350
Heavy flint......	.037	17.51	454	435	414	395	377	354	337
Extra heavy flint	.033	15.03	434	412	389	368	347	321	302

relieved in a given time, as calculated by equation (7c). It is interesting to note that the time of release of a given fraction of the stress (or path difference) depends upon the magnitude of the initial stress. Thus it takes only one-half as long to change the stress (in optical units) from $800\mu\mu$ to $400\mu\mu$ as from $400\mu\mu$ to $200\mu\mu$. The annealing times given in Table V are for the specific case of reduction of stress from $50\mu\mu$ per cm. to $2.5\mu\mu$ per cm., which, as will appear later, is of especial importance in the annealing of optical glass.

Comparison with the Results of Other Investigators.—Schott was one of the first to study the annealing of glass. In order to ascertain the best conditions for cooling various kinds of glass without the production of stress, highly stressed cylinders of the

temperature (20°) ; (2) the measurement of the time required for the disappearance of the stress when the glass is maintained at various temperatures; and (3) the determination of the dependence of these factors on the chemical composition of the glass.

The earlier measurements (by Zschimmer) were made with centimetre-cubes of two kinds of glass, one a very light barium crown and the other a flint similar in composition to our medium flint. The strain produced by sudden cooling from various temperatures is recorded by means of photographs of the cube between crossed nicols. The annealing times at various temperatures, as given for the two glasses, were obtained by bringing the cubes rapidly up to the desired temperature and noting the time when the birefringence was judged to have completely disappeared. In the more extensive measurements of Zschimmer and Schulz the birefringence was measured quantitatively by a method which gave very sharp and narrow interference bands. Results are given for the strain produced by the sudden cooling of about 25 different kinds of optical glass in the form of blocks, usually $4 \times 4 \times 24$ mm. in size. The relation between F, the stress (birefringence) and θ, the temperature from which the glass is cooled, is expressed by the empirical equation

$$(\theta_0 - \theta)(F + F_0) = C$$

in which θ_0 is a certain temperature called the " softening temperature" and F_0 and C are constants. This formula is not applicable for temperatures immediately below θ_0, while above the " softening temperature " the strain produced is practically independent of the temperature.

The data of Zschimmer and Schulz give valuable information concerning the minimum temperatures at which strain may be introduced by cooling. Unfortunately, however, the chemical compositions of the glasses are not specified (except for the flints, the lead contents of which are given), and the cooling rates are not recorded, and could be ascertained only by supplementary experiments. On the other hand, the results of Zschimmer [36] on the rate of disappearance of stress at constant temperature suffer from the disadvantage inherent in any method whereby the bire-

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[36] Zschimmer : *Loc. cit.*, p. 12.

fringence is observed only qualitatively and not actually measured.

The first investigator to attack in a really comprehensive manner the problem of glass-annealing was Twyman,[37] who realized that the viscosity of the glass was the property of fundamental importance. The mobility or viscosity was measured by supporting a strip of glass at one end and loading it at the other with a known weight, and measuring the rate of fall of the weight when the strip was maintained at known constant temperatures. From the stress, F, the rate of fall, $\frac{ds}{dt}$, and the known value of the modulus of elasticity E, the " time of relaxation " T was calculated from the relation [38]

$$T = \frac{F}{E} \frac{dt}{ds}$$

Then assuming that $\frac{dF}{dt}$ is proportional to F, the value of T was used with Maxwell's equation,

$$\frac{F}{F_0} = e^{-\frac{t}{T}} \tag{9}$$

to calculate the rate of release of stress in unannealed glass.

As mentioned above, the assumption on which this equation is based is not entirely justified, and, at least for the amounts of stress usually encountered in optical glasses, the equation fails to fit the facts. We should expect, therefore, to find material differences between the annealing temperatures, as determind by Twyman's method, and those determined by direct observation of the rate of release of stress in unannealed glass. A comparison of the two methods for the same kind of glass would be extremely interesting, but Twyman gives in his paper only a single observation for a glass of unstated composition.

The temperatures at which strain disappears rapidly when glass is heated at a rate of a few degrees per minute was determined by Morey and Wright at the plant of the Bausch and Lomb Optical Company. For four glasses, similar but not identi-

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[37] F. Twyman: " The Annealing of Glass." *J. Soc. Glass Techn.,* **1,** 61–73 (1917).

[38] See footnote on page 617. *T* may be defined as the time which would be required to reduce the stress to zero if dF/dT remained constant.

cal with the glasses described in Table I, the temperatures were as follows:[39]

Ordinary crown	540°	(573)
Light barium crown	600°	(606)
Borosilicate crown	590°	(599)
Light flint	[<500°]	(461)

These values show a rough agreement with the figures in parenthesis which are the temperatures (taken from Table V) at which, according to our measurements, the stress would be reduced in two minutes to the very small amount, $2.5\mu\mu$ per cm., if the initial stress be assumed to be $50\mu\mu$ per cm. Morey and Wright also state that in borosilicate crown the strain disappears in a few hours at 550°; over night at 510° and not in 16 hours at 480°. From equations (7c) and (8) and the values of M_1 and M_2 in Table V we note that borosilicate glass would be annealed (from $50\mu\mu$ to $2.5\mu\mu$ per cm.) at 550° in 0.96 hours, at 510° in 15.2 hours, and at 480° in 120 hours.

The temperatures of rapid release of internal stress have also been measured by English and Turner,[40] who used cylinders 8 mm. in diameter and 30 mm. long, with plane polished ends. The stress as observed qualitatively by the optical method was found to disappear rapidly at the temperatures given in Table VI. The first 13 glasses in the table are lime-soda glasses of varying composition. No. 10, which most nearly resembles our ordinary crown, anneals rapidly at 581°, while according to Table V the annealing temperature (for $t = 2$ min.) of the ordinary crown is 573°. The results of English and Turner, like the results of the other observers mentioned above, do not furnish complete information concerning the annealing process, but data such as those in Table VI afford a valuable comparison between the annealing constants of various glasses.

The most recent investigation of the annealing of glass is

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[39] From a private communication to the authors. The greatest difference in composition between these glasses and those used by us occurs with the ordinary crown. That used by Morey and Wright contained 10.2 per cent. (CaO + BaO), and 20.7 per cent. ($Na_2O + K_2O$), while ours contained 12 per cent. (CaO) and 15 per cent. ($Na_2O + K_2O$).

[40] Solomon English and W. E. S. Turner: *J. Soc. Glass Techn.*, **2**, 90–102 (1918); **3**, 125–128 (1919).

that carried out by Tool and Valasek.[41] The "annealing temperatures" were determined by heating glass cylinders 2 cm. in diameter at a rate of $2°$ per min. and noting the temperature at which a diminution in birefringence was first perceptible. Six of the nine optical glasses investigated by Tool and Valásek resemble in composition those described in this paper. It is difficult, however, to compare their results with ours except to note that their "annealing temperatures" for the six glasses are in some cases higher and in other cases much lower than the temperatures (as given in the fourth column of Table V) at which, according to our results, strain disappears very rapidly.

TABLE VI.

Determinations by English and Turner of the Temperature of Rapid Release of Stress in Glass.

| No. | CaO | Chemical composition [a] | | | | | "Annealing" temperature |
		Na_2O	Al_2O_3	B_2O_3	SiO_2	
1	0.21	25.34	0.24	. . . . .	74.05	483
2	1.50	23.80	0.20	. . . . .	73.92	490
3	2.61	23.00	0.21	. . . . .	74.08	492
4	3.81	21.50	0.28	. . . . .	74.07	503
5	4.50	20.78	0.38	. . . . .	73.78	512
6	6.26	19.38	0.58	. . . . .	73.18	526
7	7.45	17.20	0.30	. . . . .	74.41	538
8	8.16	16.00	0.31	. . . . .	74.99	552
9	9.36	14.88	0.42	. . . . .	74.96	562
10	10.38	14.22	0.45	. . . . .	74.59	581
11	11.68	13.02	0.38	. . . . .	74.93	601
12	18.17	12.72	1.41	. . . . .	66.71	608
13	17.38	11.22	0.50	. . . . .	69.73	613
14	7.00	11.50[b]	10.00	7.00	64.00	630
15	2.00[c]	8–9[b]	10.00	7.00	70.00	635
16	. . . . .	10.00[b]	2.00	23.00	65.00	585–590
17	17–30[d]	11–15[b]	. . . . .	. . . . .	57–64	450–460

[a] Small amounts of MgO, Fe_2O_3, and As_2O_3 are omitted from the table.
[b] Na_2O and K_2O.
[c] ZnO.
[d] PbO.

Tool and Valasek determined the rate of relaxation of stress at various temperatures both by the optical method (diminution of birefringence) and by mechanical methods (stretching or bending of rods), and calculated the "relaxation time," T, from

[41] A. Q. Tool and J. Valasek: *Trans. Am. Inst. Min. Met. Eng.*, 1945–1952 (1919). *Bull. Bureau of Standards*, 15, 537–571 (1920) (Sci. Paper No. 358).

Maxwell's relation (see equation 9 above). They find that the values of T obtained by the two methods do not agree and that in general T is not independent of the initial stress; *i.e.*, larger stresses relax more quickly and smaller stresses more slowly than would be expected from the extrapolation. This observation is in accord with our conclusion (see above) that $\frac{dF}{dt}$ is proportional not to F but to F^2. Tool and Valasek have also made some interesting observations on the absorption and evolution of heat in glass at those temperatures at which softening begins. This heat effect was observed in 1905 by Day and Allen in connection with a study of the crystallization phenomena of borax glass. Day and Allen state that:

" On every occasion when the borax glass was heated rapidly, either powdered or in the solid block, a slight but persistent absorption of heat appeared in the same region [490° to 500°] and continued over some 20°, after which the original rate of heating returned." [42]

The same effect has also been observed by So [43] for various glasses and found to occur at about the temperature at which stress disappears rapidly. In this same range of temperature So observed also a longitudinal contraction of glass rods upon heating but not upon cooling. Tool and Valasek observed an evolution of heat when the glass was cooled as well as an absorption of heat on heating. This effect begins at about the same temperature as that at which an increase in the thermal expansion was found by C. G. Peters. They have suggested that since the thermal effects occur at about the softening point of the glass, the annealing temperature of glasses may be estimated by determining the temperatures at which the heat absorption or evolution takes place.

The change with temperature of the rate of release of stress was found by Tool and Valasek to follow Twyman's empirical relation (see equation 8 above), and for the various glasses the rate of annealing was found to double for each 7° to 9° rise in temperature; whereas Twyman found the interval to be 8°, and, as stated above, according to our measurements this temperature increment varies between 8° and 11° for the various glasses.

(To be concluded.)

[42] A. L. Day and E. T. Allen: " The Isomorphism and Thermal Properties of the Feldspars." Carnegie Institution of Washington, Publ. No. 31, p. 34.

[43] Masamichi So: *Proc. Tokyo Math. Phys. Soc.,* **9**, 425–442 (1918).

Isotopy.—The general history and theory of isotopy is discussed by J. F. CORRIGAN (*Chem. News*, 1920, cxxi, 88, 102). He states that one of the earliest indications of the theory was pointed out in 1887, when Crookes noted the closeness of the atomic weights of the rarer elements, and put forward the view that these might be modifications of a single element. He separated yttria into several components, each marked by a different spectrum, but differing only minutely in chemical properties. For such conditions, Crookes proposed the title *meta-elements*. The suggestion did not meet with much success. The discovery of the phenomena of radio-activity gave a new impulse to speculations in this field. The first suggestion of explanation was in Soddy's theory of atomic disintegration, the old idea of the atom being, however, retained. Abegg's theory of valency came in as a further explanation of the observed phenomena. In this it is assumed that each element possesses two kinds of valencies, normal and contra, which are electrically different, the normal valencies being positive in the metals and negative in the non-metals. Corrigan discusses at some length these questions. The term " isotope " as applied to elements which although possessing different atomic weights fall into the same place in the periodic table, was first suggested by Soddy. For elements, such as mesothorium II and radiothorium, which, although possessing similar atomic weights, fall into different groups, the term " isobars " has been suggested, but it is to be hoped will not be adopted, as the word has already been appropriated in meteorology. Isotopy in lead has been especially the subject of investigation.

In conclusion, Corrigan says that the facts that have recently been made known have revived the " whole-number " theory, first suggested in the early part of the last century, by William Prout. Elements that show fractional atomic weights on even the most careful estimation may be mixtures of several modifications, but a question is at once suggested, as to why these modifications always occur in such proportions that the atomic weight of the element is so nearly the same in all cases so far determined. The subject is evidently in its incipiency, and before long interesting and striking developments may be expected.

H. L.

THE SCATTERING OF X- AND γ-RAYS.*

BY

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INTRODUCTION.

In 1912, the writer [1] published evidence which left practically no doubt that X- and γ-rays were of the same nature. That this nature is that of light has since been proved by the researches of Laue [2] and Friedrich and Knipping.[3] X- and γ-rays differ from ordinary light because of their much smaller wave-lengths, the work of Moseley [4] and Rutherford and Andrade [5] showing that we can take 10^{-7} to 10^{-10} cms. as rough limits for the wave-lengths of these rays. W. H. Bragg and W. L. Bragg,[6] Moseley and Darwin,[7] Duane,[8] and others have shown that the spectrum of any beam of X-rays consists of a continuous one with a line spectrum superimposed on it. That given in Fig. 1 is not supposed to fit any actual case, but suffices to draw attention to these facts. Each " line " is probably of definite width and forms in itself a continuous spectrum of narrow range. The ordinary continuous spectrum is due to what is called the independent or general radiation, the line spectrum to the characteristic X radiation of the material emitting the rays.

It is necessary to draw attention to the method of obtaining wave-lengths, introduced by W. L. Bragg.[9] In this method, a narrow beam of X-rays from the source S (see Fig. 2) is allowed to fall on a natural face of a crystal C at a glancing angle θ. A beam of wave-length λ will in general be reflected from the crystal.

* Communicated by Prof. A. S. Eve, Corresponding Member, Associate Editor.

[1] Gray, *Roy. Soc. Proc., Series A*, vol. lxxxvii, p. 489, 1912.

[2] Laue, *Kön. Bay. Ak.*, p. 303, 1912.

[3] Friedrich and Knipping, *Kön. Bay. Ak.*, p. 311, 1912.

[4] Moseley, *Phil. Mag.*, **27**, p. 703, 1914.

[5] Rutherford and Andrade, *Phil. Mag.*, **28**, p. 263, 1914.

[6] Bragg, W. H., and Bragg, W. L., *Roy. Soc. Proc., Series A*, vol. lxxxviii, p. 428, 1913.

[7] Moseley and Darwin, *Phil. Mag.*, **26**, p. 210, 1913.

[8] Duane, *Phys. Rev.*, **6**, p. 166, 1915.

[9] Bragg, W. L., *Camb. Phil. Soc.*, vol. xvii, p. 43, 1912; *Nature*, Jan. 23, 1913.

As the constituents of the crystal are arranged in layers or planes parallel to the face of the crystal, $\lambda = 2d \sin \theta$, where d = distance between successive planes. The waves from successive planes reinforce each other much in the same way that, in an ordinary diffraction grating, waves from successive lines of the grating reinforce each other. The modern theory of white light, of which a very full account is given in Schuster's " Optics," maintains that,

Fig. 1.

Wave Length
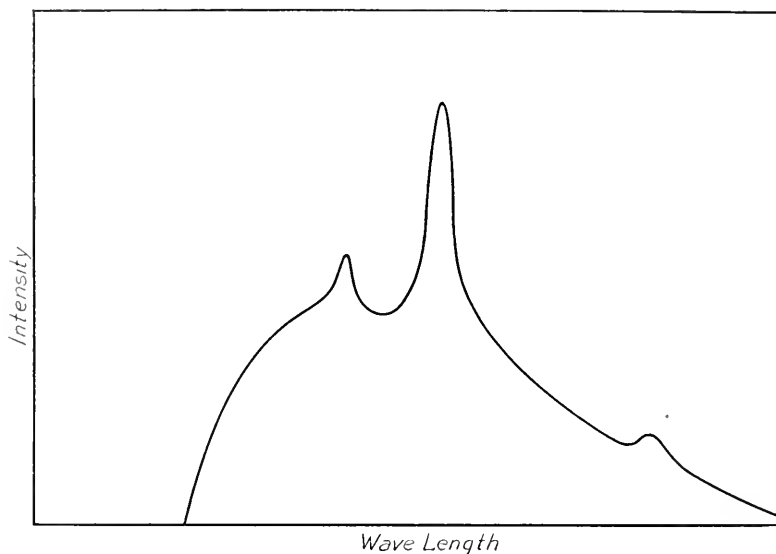
when this light falls on a grating, the periodicity in a beam, diffracted in a definite direction, is manufactured by the grating. Similarly, we believe that the periodicity in a reflected beam of X-rays is manufactured by the crystal used. With this limitation, we will speak of the average wave-length of a beam of X-rays. Rutherford and Andrade [10] have shown that penetrating γ-rays have a much smaller average wave-length than ordinary X-rays, but there is otherwise no distinction between the two types of rays.

If a beam of X-rays (the primary rays) strikes any substance (the radiator), three types of rays are emitted in all directions

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[10] Rutherford and Andrade (*loc. cit*).

from it, scattered X-rays, characteristic X-rays and electrons
moving at high speed, which we can call secondary β-rays. Scat-
tered X-rays do not depend in quality on the nature of the radi-
ator, at least only to a small extent. They do depend in quality,
however, on that of the primary rays. They have been exam-
ined by Barkla,[11] Barkla and Ayres,[12] Crowther,[13] Sadler and
Mesham,[14] and others. The views of most writers about the
quality of scattered X-rays have been well summed up by G. W. C.

FIG. 2.
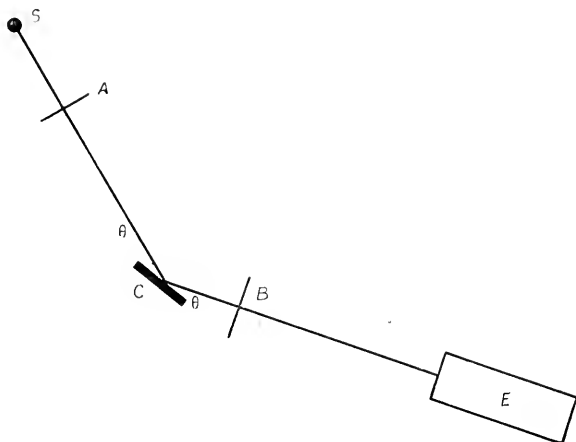
Kaye in his book on " X-rays." " All substances, when ex-
posed to a beam of X-rays, themselves give out X-rays, which
are identical with the primary rays in quality, and can in fact be
conveniently   regarded   as   so   many   unchanged   primary
rays, which have been merely scattered or deviated by the
substance."

Sadler and Mesham, however, considered that scattered
rays were less penetrating than primary rays and the writer,[15]
using as primary rays the γ-rays of radium $(B + C)$, showed
that the scattered rays were of quite a different type to
that of the primary rays, the quality of the rays de-

[11] Barkla, *Phil. Mag.,* **7,** p. 543, 1904; **21,** p. 648, 1911.

[12] Barkla and Ayres, *Phil. Mag.,* **21,** p. 270, 1911.

[13] Crowther, *Roy. Soc. Proc. Series A,* vol. lxxxv, p. 29, 1910.

[14] Sadler and Mesham, *Phil. Mag.,* **24,** p. 138, 1912.

[15] Gray, *Trans. Roy. Soc. Canada,* May, 1913; *Phil. Mag.,* **26,** p. 611, 1913.

pending also on the angle of scattering. Florance [16] had previously shown that the scattered rays in this case became less and less penetrating than the primary rays, the greater the angle of scattering. The usually accepted explanation [17] of this phenomenon is that, as the primary rays are heterogeneous, softer rays are scattered relatively more strongly at larger angles than harder rays. This has very little to do with the result, however, the softer rays being produced from harder rays during the process of scattering. In a later paper Florance [18] recognized that soft rays were produced in this way.

We have, therefore, these two quite distinct views about the quality of the scattered radiation, and as very few writers are aware that there is a change in quality in the scattered rays, depending on the angle of scattering, a discussion will be given below, which, it is hoped, will make this point quite clear. The problem is one of great theoretical importance and will be discussed as indicated below :

Quality of Scattered Radiation.
Distribution of Scattered Radiation.
Effect of Scattering in Absorption Problems.
Theoretical Considerations.
Summary.

Before proceeding to this discussion, it is thought advisable to draw attention to the figures in the table below obtained from

TABLE I.

Type of Radiation	Average Wave Length	Mass Absorption Coefficient				
		Carbon	Alumi-num	Iron	Copper	Lead
Iron X-rays K series	1.8×10^{-8} cm.	10.0	88.5	66.1	95.1	about 400
Silver X-rays K series	0.53×10^{-8} cm.	0.46	2.5	17.4	22.7	about 70
Reflected X-rays....	0.244×10^{-8} cm.	....	0.493	2.88	3.84	11.2
Hard γ-Rays of radium D..........	....	0.116	0.380	2.80	....	11.2
Reflected X-rays....	0.160×10^{-8} cm.	....	0.178	0.64	0.79	1.88
X-rays excited in lead by β-rays of radium E..........	....	0.074	0.124	0.64	....	3.7 to 0.16
γ-rays of radium C...	$< 10^{-9}$ cm.	0.041	0.041	0.041	0.041	0.042

[16] Florance, *Phil. Mag.*, **20**, p. 921, 1910.

[17] Compton, A. H., *Phys. Rev.*, **14**, p. 20, 1919; see also Florance (*loc. cit.*), and Oba, *Phil. Mag.*, **27**, p. 601, 1914.

[18] Florance, *Phil. Mag.*, **27**, p. 225, 1914.

information given by Barkla and Collier,[19] the writer,[20] Rutherford and Richardson,[21] Rutherford and Andrade,[22] and Hull and Rice.[23] By reflected X-rays, we mean X-rays obtained by reflection from crystals.

Apparent discrepancies will be noted in the figures for aluminum. These, however, are due to the fact that absorption coefficients have been obtained by two different methods, which we will call method 1 and method 2. In method 1,

FIG. 3.
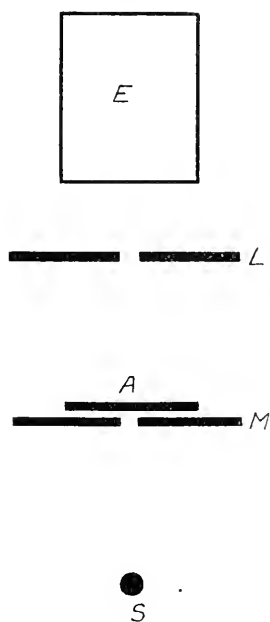
(see Fig. 3), the rays from the source S pass through holes in the lead screens L and M, so that characteristic and scattered X-radiations emitted from the absorption plate A, of thickness x, say, cannot enter the electroscope E. If $I_o =$ the original intensity, I_1 the intensity of the rays after passing through the absorption plate and we write $I_1 = I_0 e^{-\mu_1 x}$, then $\mu_1 =$ the average

[19] Barkla and Collier, Phil. Mag., 23, p. 987, 1912.
[20] Gray, Roy. Soc. Proc. Series A, vol. lxxxvii, p. 489, 1912.
[21] Rutherford and Richardson, Phil. Mag., 25, p. 722; 26, p. 324, 1913.
[22] Rutherford and Andrade (loc. cit.).
[23] Hull and Rice, Phys. Rev., 8, p. 326, 1916.

absorption coefficient of the rays in the plate A. The absorption is due to different processes and it is usual to write $\mu_1 = \tau + \sigma$. The coefficient τ gives a measure of the absorption due to the ejection of secondary β-rays and to the formation of X-rays characteristic of the absorbing material. On the other hand, σ gives a measure of the absorption of the primary rays due to scattering in the absorber. To compare different materials we write

$$\frac{\mu_1}{\rho} = \frac{\tau}{\rho} + \frac{\sigma}{\rho}$$

where ρ = the density of the plate A. The quantity $\frac{\mu_1}{\rho}$ is called the mass absorption coefficient and $\frac{\sigma}{\rho}$ the mass scattering coefficient.

In method 2, (see Fig. 4), we have no plates such as L and M

FIG. 4.
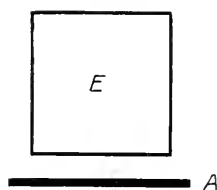
defining the rays, and the plate A is placed under the electroscope E. If, now, I_2 = the intensity of the rays after passing through A we may write

$$I_2 = I_0 e^{-\mu_2 x},$$

where μ_2 is again called the absorption coefficient, although, strictly speaking, this is not accurate. As, in this case, emergent scattered radiation enters the electroscope E, it is evident that μ_2 is less than μ_1 the correct value. This fact is brought out by the figures in the above table (those for γ-rays and X-rays excited by β-rays

having been obtained by the second method), and also in some given by Ishino.[21] The method, however, is a very useful one and if σ is small compared with τ, μ_2 is practically equal to μ_1. Writing in general $I = I_0 e^{-\mu x}$ we see that if μ is constant,

FIG. 5.
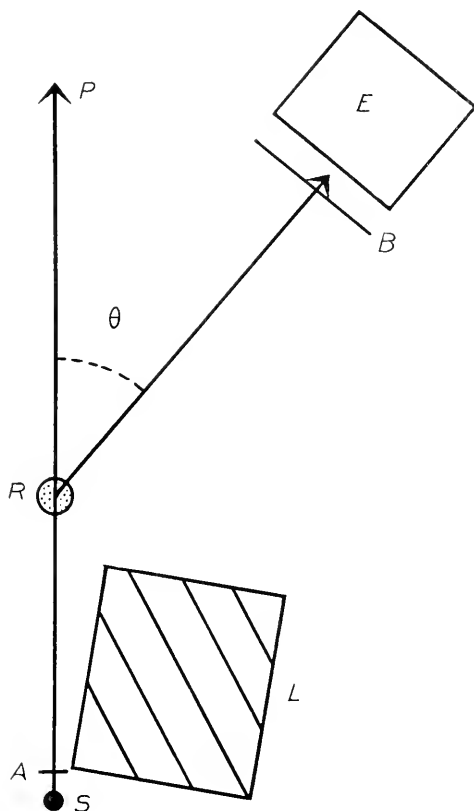
$\log I + \mu x = \log I_0$, so that if $\log I$ is plotted against x the resulting curve is a straight line.

The table shows that, as the average wave-length of a beam decreases, its penetrating power on the whole increases. It is also desired to draw attention to the fact that, while carbon absorbs the γ-rays of radium D about three times as much as the γ-rays of radium C, lead absorbs the former rays over two hundred times as much.

[21] Ishino, *Phil. Mag.*, **33**, p. 140, 1917.

QUALITY OF THE SCATTERED RADIATION

When we wish to compare the qualities of two different beams, we should obtain their spectra, but this is often impracticable. In experiments on the scattering of X-rays, such a comparison has invariably been made by absorption measurements. The disposition of apparatus used in experiments on scattering is shown in Fig. 5. A beam of X-rays from the source S is allowed to fall on the radiator R. A measure of the quality, and of the relative intensity I_θ of the rays scattered in a direction making an angle θ with that of the primary beam, can be obtained

FIG. 6.

Thickness of Lead in Cms
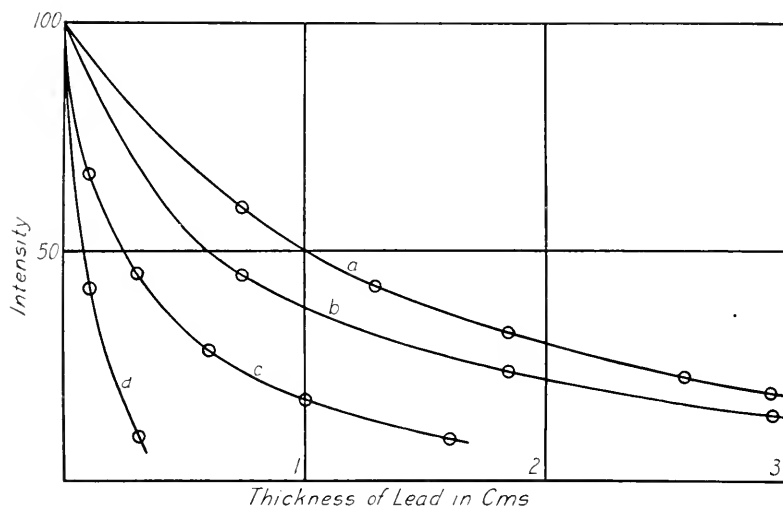
by means of the electroscope E. It is necessary to screen the electroscope E from the direct rays, and when the primary rays are the γ-rays of radium $(B + C)$, a thick block of lead L is used for this purpose. In the writer's experiments, the active material S consisted of 15 milligrams of radium bromide enclosed in a lead cylinder 1.7 mm. thick.

Some of the results obtained are shown in the curves of Figs. 6 and 7. Curve (a) refers to the absorption of the primary rays, curve (c) to the absorption of the rays scattered through 50°, the absorbing material being placed in front of the electroscope, and curve (d) refers to the absorption of rays scattered through 110°. Curve (b) enables us to find the relative intensity of the

rays scattered through 110°, after different thicknesses of lead are placed in front of the source S (position A). The corresponding curve for 50° would lie between curves (a) and (b). In Fig. 6 the intensity is plotted against the thickness of absorbing material, and in Fig. 7 the logarithm of the intensity to the base 10 is plotted instead.

That the scattered rays are less penetrating than the primary is at once evident. For example, we find that 3 mm. of lead reduces the primary rays to 80 per cent., rays scattered through 50°

FIG. 7.

Thickness of Lead in Cms.
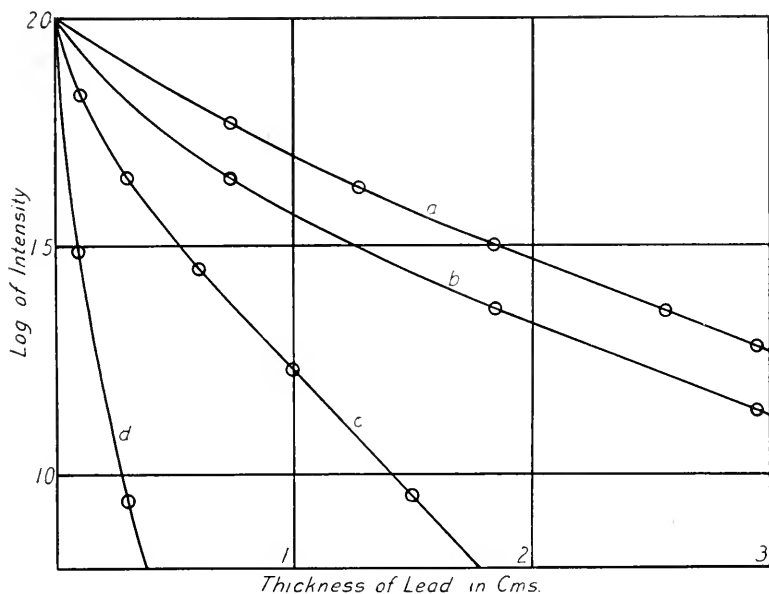
to 45 per cent., and rays scattered through 110° to 10 per cent. of their original intensities. We would therefore expect that, if no modification in the rays is produced by scattering, an extra 3 mm. of lead placed in front of the active material would again reduce the relative intensities of the three types of radiation to 80 per cent., 45 per cent., and 10 per cent., respectively. The following analysis will make this clearer, and will prove, with the information given later, that the scattered radiation we are examining is not due to reflection at crystalline facets inside the radiator.

We will suppose that the primary radiation consists of two types, one soft, one hard, of intensities I_1, I_2, respectively. We will also suppose that no change in either type is produced by scattering. If these rays fall on the radiator R, the intensity of the rays scattered through an angle θ, say, and entering the electroscope E (Fig. 5) may be written equal to $k_1I_1 + k_2I_2$. The coefficients, k_1, k_2, will depend both on the type of radiation and on the absorption of both primary and scattered rays in the radiator. If we have a lead plate which transmits a fraction p_1 of soft rays, p_2 of hard rays and place it in position B (see Fig. 5), the intensity of the scattered rays entering the electroscope E will equal $p_1 k_1 I_1 + p_2 k_2 I_2$. If, on the other hand, the absorption plate is placed in position A, the intensity of the rays striking the radiator would equal $p_1 I_1 + p_2 I_2$, and the intensity of the scattered rays entering the electroscope will again equal $p_1 k_1 I_1 + p_2 k_2 I_2$.

On placing an extra 3 mm. of lead in front of the source S, however, we find that the rays scattered through 50° are reduced to 75 per cent. and not 45 per cent., and the rays scattered through 110° to 70 per cent. and not 10 per cent. of their original intensities. In the original paper, the writer drew attention to the fact that soft γ-rays were scattered more effectively than hard γ-rays, and this explains why we get a larger reduction in the intensity of scattered rays than we do in the primary rays. However, curve (b) (Fig. 7) shows that, after the primary rays have passed through a thickness of lead greater than about 1.5 cm., the intensity of the scattered radiation is proportional to the intensity of the primary rays. This happens when the bulk of the rays from radium B have been absorbed. Further, on examination, we always find great differences in penetrating power between primary and scattered rays, similar to those indicated by curves (a), (c), and (d). This variation of quality with the angle of scattering, and the fact that it is approximately independent of the nature of the radiator, show that the effect we have observed is not due to the formation of characteristic radiations in the radiator. We conclude, therefore, that in some way an ordinary beam of γ-rays is changed in quality when scattered, the change depending on the angle of scattering.

The writer had intended to use, as primary rays, X-rays reflected from a crystal, but it was not until after demobilization last year, that he was able, through the kindness of Sir William

Bragg and the British Scientific and Industrial Research Council, to carry out further experiments at University College, London. In the time at his disposal he was not able to obtain a reflected beam of sufficient intensity to work with satisfactorily. However, one that was approximately homogeneous, according to measurements of penetrating power and wave-length, was obtained by filtering X-rays through a sheet of tin. This beam was tested as follows. After it had passed through various thicknesses of aluminum, the percentage transmitted by a sheet of aluminum 1.63 mm. thick was found. This percentage has been plotted against the corresponding thickness passed through in

Fig. 8.

Thickness of Aluminum
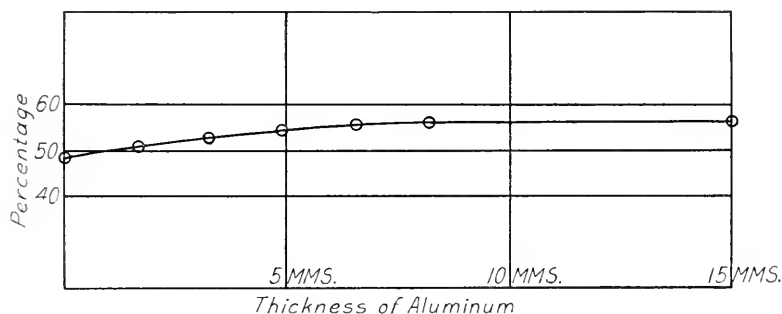
Fig. 8. It will be noted that the penetrating power of the beam becomes very nearly constant after passing through 7 mm. of aluminum. The scattered rays were again found to be more absorbable than the primary rays. For example, under these circumstances, rays scattered through 35° have an absorption coefficient in aluminum 6 per cent. greater than that of the primary rays; rays scattered through 70°, an absorption coefficient 12 per cent. greater; and rays scattered through 110°, one 18 per cent. greater. The increase is thus approximately proportional to the angle of scattering. It also appeared to be independent of the thickness of aluminum passed through.

These experiments, which will be discussed in greater detail in a later paper, verify the previous results obtained with γ-rays, although, in the latter case, the comparative softening of the scattered rays is much more marked. Curves (a) and (c) (Fig. 7) indicate that, in this case also, scattered rays are always less penetrating than primary rays no matter how much absorbing ma-

terial the rays pass through. This point is of importance, as it indicates that the smaller wave-lengths in the spectrum of the primary rays would be absent in the spectrum of the scattered rays.

The results we have obtained would be explained if we could always look on a beam of X- or γ-rays as a mixture of waves of definite frequencies, and if rays of a definite frequency were altered in wave-length during the process of scattering, the wave-length increasing with the angle of scattering. But we may not always be justified in looking on a beam of X-rays in this way or, in other words, we may not always be able to estimate the properties of such a beam by Fourier analysis. We have very little idea of the actual mechanism by which X-rays are produced from β-rays, but it seems probable that X-rays consist rather of a series of thin pulses than of regular waves occurring in trains of great length. As stated above, the periodicity in a beam reflected from a crystal is doubtless produced by the crystal itself.

Recently, the writer [25] has shown that when the β-rays of radium E excite X-rays, the bulk of the energy of the X radiation formed by a β-ray travels on in directions very close to that of the β-ray. This remarkable result indicates that there is nothing of a vibratory character in the source of the X radiation. Therefore we consider that X-rays are emitted in the form of thin pulses and, as the diameter of an atom is of the order of 10^{-8} cms., the thickness of a pulse would be of that order.

The following calculation may be of interest. Suppose we pass a current of 1.6 milliamperes through an X-ray tube. This would mean that

$$\frac{4.8 \times 10^{6}}{4.8 \times 10^{-10}} \text{ or } 10^{16}$$

electrons would hit the anticathode per second. Experiment indicates that only a small fraction of these electrons give rise to X-rays. Let us suppose that, at most, one in a hundred do so. 10^{14} pulses would then be emitted per second, and as such pulses travel at the rate of 3×10^{10} cms. per second the average distance between pulses would be 3×10^{-4} cms. The average distance between pulses is, therefore, much greater than the average thickness of a pulse. The actual form of a pulse we do not know, but for purposes of illustration we can imagine it to be of the shape indicated by Fig. 9, in which, at some definite time, the electric displacement in

[25] Gray, *Proc. Roy. Soc.*, Series A, Vol. 86, p. 513, 1912.

the pulse is supposed plotted against the distance from its origin, the pulse travelling on unchanged in form when not passing through matter. If two similar pulses pass over a point simultaneously, then the thickness of the combined pulse will be the same as before, but its intensity will be four times that of a single pulse just as is the case when two waves of the same length and in the same phase reinforce each other. If the two pulses are slightly out of step, the resultant pulse will be slightly thicker and less penetrating and the resultant intensity will be less than four times that due to a single pulse.

Later on we will consider, briefly, from a theoretical point of

FIG. 9.
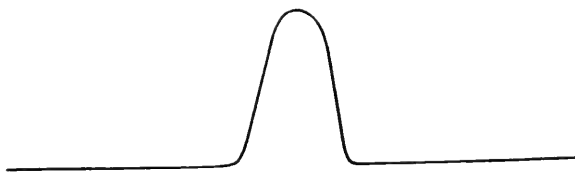
view, the scattering of such a pulse, and also of a train of waves of definite wave-length. It appears to be possible to explain the effect we have observed if the primary rays consist of a series of pulses, but not if the primary rays consist of a wave train of definite wave-length. That reflected rays differ from ordinary scattered radiation is evident from an experiment of Moseley's and Darwin's.[26] They found that when the same absorption plate was placed in positions A and B (see Fig. 2) the electroscope reading was the same in both cases. When we are measuring ordinary scattered radiation and use an absorbing screen in which a negligible amount of its characteristic radiation is excited, the intensity as registered by the electroscope is invariably greater when the plate is placed in position A. We have seen above, for example, that in the case of the scattering of the γ-rays of radium, for an angle of scattering of 110° and an absorption plate of lead 3 mm. thick, the intensity is about seven times as much when the lead is placed in position A. Finally, the writer understands that further experiments at University College, London, have proved directly that a wave train of definite wave-length is not altered in wave-length by scattering.

[26] Moseley and Darwin (loc. cit.).

DISTRIBUTION OF THE SCATTERED RADIATION.

In the case of ordinary X-rays, the distribution of the scattered radiation in most cases is similar to that given by Fig. 10, where I_θ is plotted against θ, the angle of scattering. For values of θ greater than 90°, $\frac{I_\theta}{I_{90°}}$ is nearly equal to but somewhat less than $(1 + \cos^2\theta)$. For angles less than 90°, $\frac{I_\theta}{I_{90°}}$ is nearly always greater than $(1 + \cos^2\theta)$. An average value of $\frac{I_{30°}}{I_{90°}}$ is about 2.10 instead of 1.75.

When the γ-rays of radium $(B + C)$ are used as primary rays, very penetrating secondary β-rays are emitted from the radiator, and it is necessary to have some absorbing material in front of the electroscope E to absorb these rays. In Florance's original experiments 3 mm. of lead was used, and the distribution apparently found by him then is given in Fig. 11. We have seen above, however, that this thickness of lead cuts down some types of scattered radiation much more than others and thus this curve is to some extent misleading. Using a carbon plate to absorb these β-rays and correcting for absorption in the radiator and carbon plate, the writer found that for carbon,

$$\frac{I_{35°}}{I_{90°}} = 2.10$$

and

$$\frac{I_{150°}}{I_{90°}} = 1.20$$

These values do not differ very much from those obtained with certain types of X-rays. They indicated for the first time that less radiation was scattered through 90° than any other angle, a point of considerable importance.

The writer believes that there are no marked differences in the distribution of the scattered radiation, whether the primary rays are soft X-rays or penetrating γ-rays. As a matter of fact, for values of θ between 30° and 110°, a range over which the writer has worked, $I_\theta/I_{90°}$ varies very little, whatever the type of primary rays. This shows that if the rays are not altered in quality by scattering, the penetrating power of the scattered rays should vary very little with the angle of scattering.

EFFECT OF SCATTERING IN ABSORPTION EXPERIMENTS.

In this section, absorption according to the second method described above will be considered. A consideration of the table and of the results given above, makes it evident that the

FIG. 10.
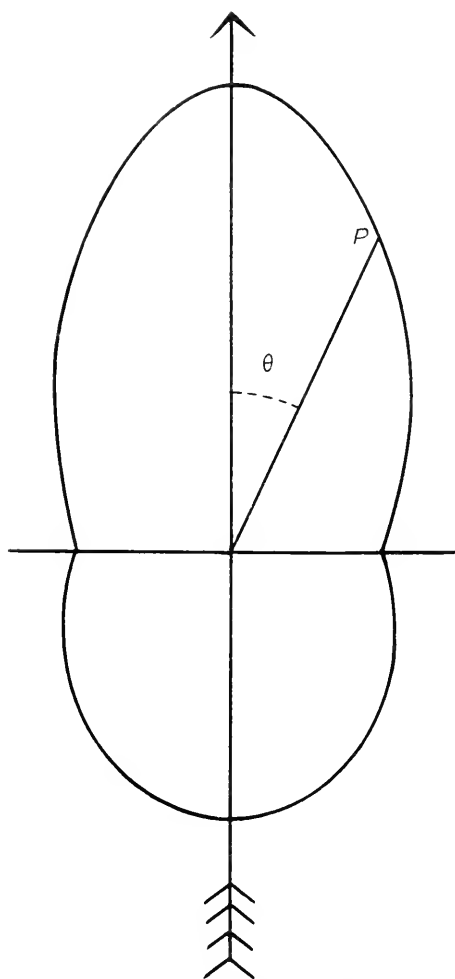
following processes are at work, when an ordinary beam of X- or γ-rays passes through matter. In the first place, we have the greater relative absorption of the softer rays, and in the second place, the reproduction of soft rays by the scattering

of the primary rays. Ultimately we would expect the two effects to balance each other, and then the absorption would become exponential. Mrs. Soddy, Soddy and Russell,[27] have shown this to be the case with the γ-rays of radium $(B + C)$ as primary rays,

FIG. 11.
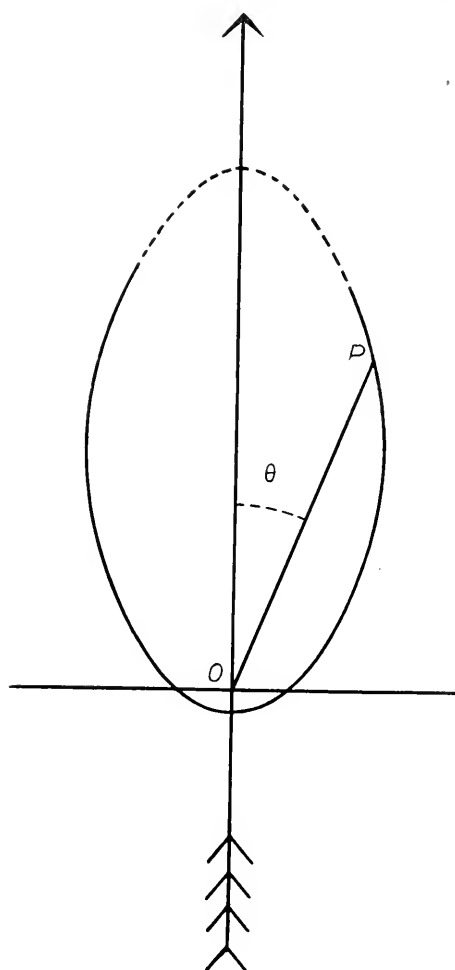
and with lead as absorbing material, for a range in thickness of 2 to 22 cms. With the same primary rays, Russell [28] found the

[27] Soddy, Mrs., Soddy and Russell, *Phil. Mag.*, **19**, p. 225, 1910.
[28] Russell, *Proc. Roy. Soc. Series A*, vol. lxxxviii, p. 75, 1912.

absorption in mercury exponential for a range in thickness of 1 to 25 cms.

With the γ-rays of radium $(B+C)$ as primary rays, it can be shown that much less scattered radiation escapes, under similar circumstances, from a lead plate than from a corresponding carbon plate. This is due to the much greater absorption of softer rays in lead. For example, it was found that two and one-half times as much scattered radiation left a carbon plate, the primary rays passing through the radiators normally and the angle of scattering being 50°. Both carbon and lead plates had about the same area of cross section, viz., 90 sq. cms., and the same mass per unit area, viz., 10 grammes. This ratio between the intensities of the scattered radiation emerging from the two plates becomes greater, the greater the angle of scattering. γ-rays exponentially absorbed by carbon will therefore be distinctly softer than γ-rays exponentially absorbed by lead, and consequently lead will harden rays exponentially absorbed by carbon, and carbon will soften rays exponentially absorbed by lead.

In the previous paper this result was stated as follows: γ-rays exponentially absorbed by materials of low atomic weight are hardened by materials of high atomic weight, and γ-rays exponentially absorbed by materials of high atomic weight are softened by materials of low atomic weight. The first point had previously been proved by Rutherford and Richardson[29] with respect to aluminum and lead and, subsequently, Oba[30] proved the second point. We see also that it is not possible to isolate what has been called the end radiation, by passing X-rays through absorption screens, because of this continuous production of softer rays.

The term exponential absorption has been somewhat loosely used. It used to be said that the β-rays of radium E were exponentially absorbed by materials of low atomic weight. The absorption of these rays by paper is shown in curve (a) (Fig. 12) in which the logarithm of the intensity to the base 10 is plotted against the mass per unit area of absorbing material. The rays appear to be exponentially absorbed over a certain range, but afterwards the absorption increases, and no rays pass through a thickness of paper greater than one corresponding to a mass per unit area of 0.48 gramme q. p. Curve (b) shows the absorption of

[29] Rutherford and Richardson (loc. cit.).

[30] Oba (loc. cit.).

β-rays reflected from a lead plate, and indicates that fast β-rays are reduced in velocity when scattered through large angles. This curve has been obtained for the writer by Miss A. V. Douglas, who is continuing the experiments. β-rays have a range because they lose energy, owing to ionising some of

FIG. 12.

Mass Per Sq Cm
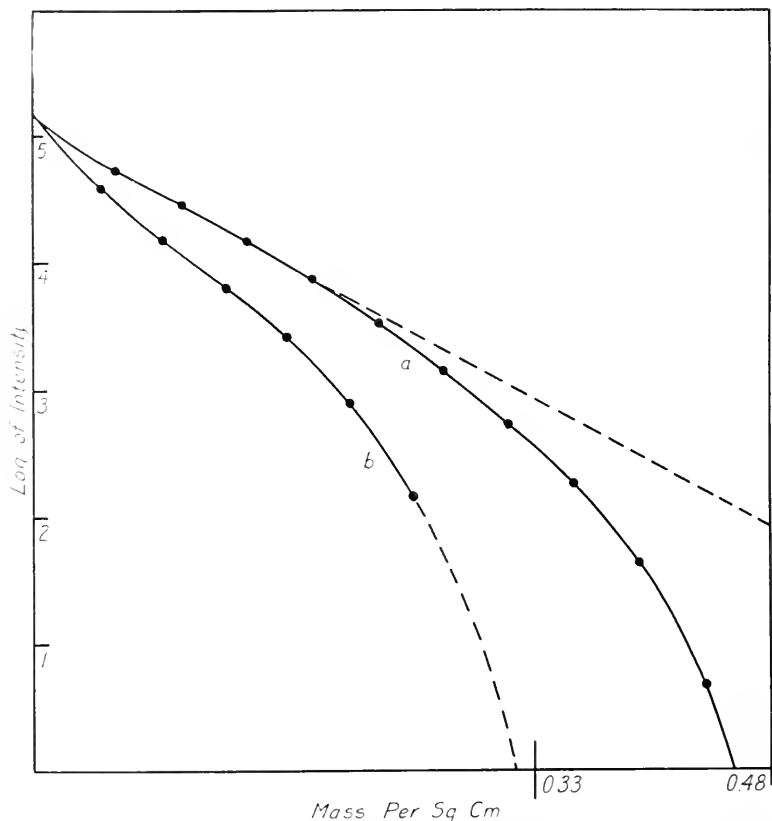
the atoms through which they pass. The writer has often wondered whether γ-rays have a range, or whether they will pass through any thickness of material provided the initial intensity is large enough. This important question has apparently been answered by Russell,[31] who found that the γ-rays of radium (B + C) could not be observed through 27 cms. of mercury, no matter how sensitive he made his measuring apparatus. His

[31] Russell (loc. cit.).

result is shown in curve (b) (Fig. 13). The second point does
not fit the curve because the corresponding intensity of the rays
was too small to be measured accurately. The points should lie
on the straight line, curve (a).

THEORETICAL CONSIDERATIONS.

The theory, which has given the best explanation of the prop-
erties of scattered radiation, was originally introduced by Sir

FIG. 13.

Thickness of Mercury in Cms
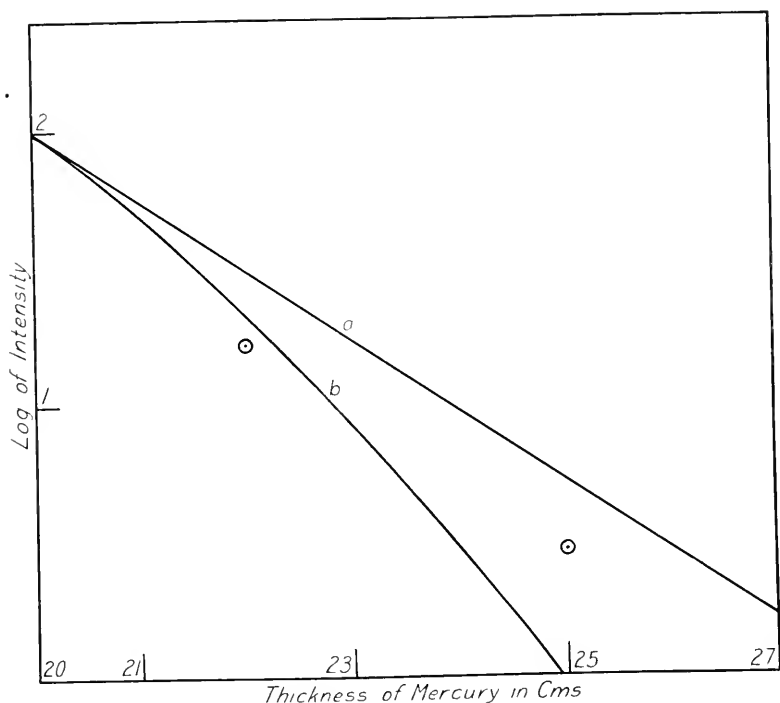
Joseph Thomson.[32] In this theory, when an electromagnetic pulse
passes over an atom, the electrons in it are accelerated and the
secondary pulses caused by the acceleration of these electrons
form the scattered radiation. Thomson considered that the forces
exerted by the primary pulses on the electrons were large com-
pared with the forces tending to keep them in their equilibrium

[32] Thomson, J. J., "Conduction of Electricity Through Gases," 2d
Edition, p. 321.

positions, and also that the electrons scattered independently of each other. Under these circumstances it can be proved that

$$I_\theta \text{ is proportional to } (1 + \cos^2\theta)$$

The next advance was made by D. L. Webster,[33] who considered that the electrons did not scatter independently of each other. He also believed that the scattered radiation should be less penetrating than the primary radiation. C. G. Darwin,[34] taking the primary rays to be of definite wave-length, obtained an expression which gave a rough qualitative explanation of the variation of the scattering coefficient, and of the distribu-

FIG. 14.
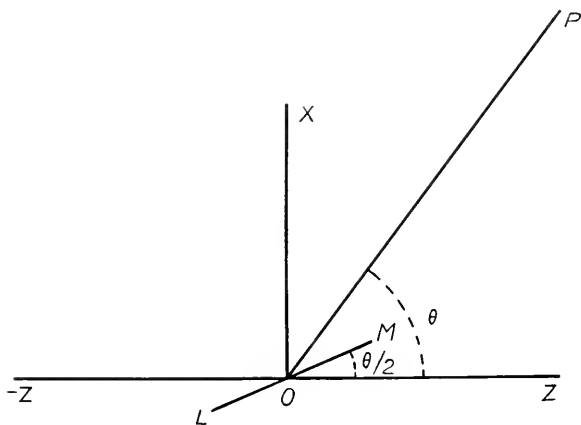
tion of the scattered radiation, with atomic weight of the radiator and wave-length of the primary beam. Finally, A. H. Compton[35] has accounted qualitatively for the very small mass scattering coefficient observed when the primary rays are the γ-rays of radium C, by assuming the electron to be a ring having a diameter comparable with the wave-length of the primary rays.

The analysis given below will bring out these points and also the differences in the scattering of rays of definite wave-length and of a single pulse. First we will suppose the primary rays to be of wave-length λ. In Fig. 14 the direction of the incident radiation is given by $-ZOZ$. We will suppose that the rays pass

[33] Webster, D. L., *Phil. Mag.,* **25,** p. 234, 1913.

[34] Darwin, C. G., *Phil. Mag.,* **27,** p. 315, 1914.

[35] Compton, A. H. (*loc. cit.*).

through an atom with nucleus at O.   It is desired to find the variation of I_θ with θ, the angle of scattering.   We will take rectangular axes at O, and a point P in the zx plane such that OP makes an angle θ with OZ. LOM represents the section of a plane perpendicular to the zx plane and making an angle $\frac{1}{2}\theta$ with the yz plane.   Finally we will suppose that the average distance of the electrons in the atom from the plane LOM, $= p$, a distance that will be independent of the angle θ.

We can get the effect of an unpolarized beam by considering two separate polarized beams of equal intensities, in one of which the direction of the electric displacement is parallel to the y axis and in the other parallel to the x axis.   The first beam will cause an electron to vibrate, with the same period as that of the primary rays, in a direction parallel to the y axis and therefore the intensity of the scattered radiation at P will be independent of θ. The second will cause the electron to vibrate in a direction parallel to the x axis and therefore the intensity of the scattered radiation at P will be proportional to $\cos^2\theta$.   The intensity of the scattered radiation at P for an unpolarized primary beam, therefore, may be written $= \dfrac{K}{r^2}\ (1 + \cos^2\theta)F(\theta)$ where $r =$ distance OP and K is an arbitrary constant.   To obtain an idea of the manner in which $F(\theta)$ varies with θ, let us consider the effect of two electrons, one on each side of the plane LOM and a distance p from it.   If $a^2 =$ intensity of the scattered radiation at P due to one of the electrons, the resultant intensity from the two will be equal to $2a^2\left\{1 + \cos\dfrac{(8\pi\,p\,\sin\frac{1}{2}\theta)}{\lambda}\right\}$, and will therefore increase as p and θ diminish, and as λ increases.   The wave-length of the scattered radiation will be the same as that of the primary radiation.   The above expression shows in general that:

(1) Mass for mass, heavy atoms scatter more effectively than light atoms, since electrons are nearer each other in the heavy atoms.

(2) X-rays of long wave-length are scattered more effectively than rays of short wave-length.

(3) $F(\theta)$ diminishes with θ and therefore that $I_{(90° - a)}$ is greater than $I_{(90° + a)}$.

When the wave-length of the incident radiation is comparable with the diameter of the electron, we can imagine that O is the centre, and our two scattering centres equal parts of the

electron, each being a distance p from the plane LOM. From this we get Compton's result that, in such a case, the scattering is less effective than when the wave-length of the incident radiation is large. For example, the resultant intensity from two such scattering centres would be proportional to

$$2 \left\{ 1 + \cos \frac{(8\pi p \sin \frac{1}{2}\theta)}{\lambda} \right\}.$$

instead of being proportional to 4.

When the primary rays consist of a series of independent pulses we can prove as before that I_θ may be written $= \frac{K}{r^2}(1 + \cos^2\theta)f(\theta)$. In this case the difference in path between scattered pulses from our two electrons will be $4p\sin\frac{1}{2}\theta$ and for very small values of p and θ, the intensity of the resultant scattered radiation will be nearly four times that from a single electron. We can see, as before, that in general:

(1) Mass for mass heavy atoms scatter more effectively than light atoms.

(2) Thick pulses are scattered more effectively than thin pulses.

(3) $f(\theta)$ diminishes with θ.

In addition, the thickness of the scattered pulse will depend on θ and will be larger the greater the angle of scattering. It would also appear as if the quality of the scattered radiation depended in general on the atomic number of the scattering atom. Again, when the thickness of the pulse is comparable with the diameter of an electron, the electron will not scatter the pulse as effectively as it would, if the thickness of the latter was large compared with the diameter. Conclusions (1), (2), (3) have been verified by experiment.

It appears, therefore, as if we must draw a distinction between the scattering of a train of waves of definite wave-length and of a pulse. Now Rutherford and Andrade have shown that the γ-rays of radium $(B + C)$ have decided line spectra, and yet we have this surprising change in quality produced by scattering. This shows that experiments on the scattering of characteristic X-rays are very necessary, for it is very difficult to believe that such rays consist of a series of pulses. The conclusion, however, that the bulk of γ radiation consists of a series of pulses may perhaps be justified.

The discussion we have given of experiments and theory is

to be regarded as a preliminary one only. It shows that the scattering of X-rays is not as simple a process as has generally been believed, and that a great deal of work needs to be done before we can properly understand the problem. Having recently obtained the necessary apparatus, the writer will continue experiments on the subject, in the hope that such experiments will add to our knowledge of radiation and atomic structure.

Before concluding this section, it is perhaps advisable to say why we have not considered the possible effect of secondary β-rays in producing " scattered " radiation. Such β-rays may excite X-rays (a) in their expulsion from atoms (b) in collisions with other atoms. Only a very small proportion of scattered radiation can, however, be formed in this way. As a rule, so many more β-rays are produced per unit mass in material of high atomic weight, and are so much more effective in producing X-rays in such materials, that we would expect a much greater variation of the mass scattering coefficient with atomic weight than we actually find. For example, the γ-rays of radium D are scattered just as effectively by carbon as by lead, and yet they must excite nearly fifty times as many β-rays in a small mass of lead as in the same mass of carbon. It is not necessary to give other reasons.

SUMMARY.

1. It has been proved, when an ordinary beam of X- or γ-rays, (*i.e.*, one not obtained by reflection from crystals), is scattered, that the rays scattered in any definite direction are of quite a different type to that of the primary rays. This type depends on that of the primary rays, the angle of scattering, and possibly on the nature of the scattering material. The effect is such that the scattered rays become less and less penetrating than the primary rays, the greater the angle of scattering.

2. The distribution of the scattered radiation for all types of X and γ radiation is similar, less radiation being scattered through 90° than in any other direction.

3. A discussion is given on the effect of scattering in absorption problems.

4. Theoretically, it appears possible to explain the results of experiment on the hypothesis that X-rays consist of a series of pulses, and evidence is given that this should be the case. When the primary rays are rays of definite wave-length reflected from a crystal, the scattered rays should be of the same wave-length.

Composition of Ancient Bronzes from the Far East.—Masumi Chikashige (*J. C. S.*, 1920, cxvii and cxviii, 917) states that bronzes are the most suitable materials from which to obtain information in regard to ancient metallurgical methods. Brass articles are not so ancient as bronze, the latter dating from before the tenth century. Excavated objects are always covered with rust, which is generally removed before making analyses, but the author thinks this inadvisable. In bronze a selective oxidation takes place in the order: copper, lead, tin. The composition of the rust will differ from that of the object, being richer in copper. Montelius gave in 1900 the following analysis to two similar Egyptian rings:

Copper	79.51	16.23
Tin	9.65	75.66

The first ring seems not to have undergone much change, but the other has lost much copper by oxidation. The author's method is to remove earthy matter but to analyze rust and metal together, but even this method is unsatisfactory when a partial solution or disintegration of the surface material has occurred. A series of analyses is given, among which is that of a white bronze mirror from the first century containing on an average as its principal ingredients, copper, 67; tin, 27; and lead, 6. The author was able to make a good mirror with these constituents. White bronze is very hard, the figures on the backs of such mirrors consisting of deeply cut lines have resisted wear for several thousand years. Arrow heads were found to contain principally copper and tin, with small amounts of antimony, iron and nickel. A Japanese bell that dates from the tenth century is principally copper and tin, but with notable amounts of lead and antimony and a small amount of nickel. Chinese coins, current from the fifth to the eighth century, B.C., show much difference in composition, the principal ingredients being copper, tin and lead with, in a few cases, appreciable amounts of iron and arsenic. Corean bronze articles were found to be largely copper and tin. This alloy is quite resistant to rusting.

H. L.

Rainfall in Hawaii. (*U. S. Geological Survey Press Bulletin No. 457, October, 1920.*)—An inch a day is the average rainfall in the upper Waipio Valley, Hawaii, which makes it one of the areas in the world where the rainfall is heaviest. On the other hand, the rainfall on some of the slopes of Hualalai, on the same island, is only 20 inches a year. The only surface streams on the island are along the northeast coast between Hilo and Kohala. Waipio River, according to the Survey, has been partly developed for irrigation.

THE MEASUREMENT OF GRAININESS IN PHOTOGRAPHIC DEPOSITS.*

BY

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WHEN a photographic deposit is examined under the micro-scope, it is found to be made up of a large number of minute particles consisting of metallic silver which have been reduced from the silver halide by the action of the developer. It is neces-sary to employ a relatively high magnification in order to resolve clearly the individual particles or grains composing this silver deposit. The size of such grains varies over a considerable range, the homogeneity of grain size being dependent upon the particular type of emulsion. Measurements have shown that these grains vary in diameter from approximately 0.5 microns in slow plates up to from 1 to 10 microns in high-speed plates. The distribution of these grains through the gelatine in which they are embedded is not absolutely uniform, there being in many cases a marked tendency for these grains to occur in groups or clumps of from five to twenty grains. Further, in some cases, these aggregates also tend to agglomerate, thus causing a further lack of homo-geneity in the appearance of the deposit.

Considerable research work has been done by various investi-gators relative to the size of grain in the undeveloped plate as well as in the deposit resulting from the development of the exposed silver halide. Practically all of this work deals with the size of the ultimate silver halide crystals or the metallic silver particles, and with the relative proportion of grains of various sizes occurring in various emulsions. In some cases a developed deposit may appear grainy (that is, lacking homogeneity) to the unaided eye. The cause of this is almost invariably due to an agglomeration or grouping of the clumps made up of several of the ultimate silver particles which of themselves are so small as to be entirely beyond the resolving power of the unaided eye.

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* Communicated by Dr. C. E. K. Mees. Communication No. 99 from the Research Laboratory of the Eastman Kodak Company.

When a deposit is viewed under magnifications insufficient to make just visible the ultimate grains, a lack of homogeneity is apparent which is due primarily to the presence of the first order clumps or aggregates composed of a few of these metallic silver particles. Under such conditions, the agglomeration of these clumps ceases to have any appreciable effect on the grainy appearance of the deposit because the magnification is sufficient to separate widely the agglomeration centres. When the magnification is increased still further so that the individual silver grains are easily visible, the graininess existing is due in a great measure to these grains themselves. It will be seen, therefore, that the lack of homogeneity in a photographic deposit depends upon various causes, according to the magnification under which the deposit is observed.

In speaking of grain, the scientific investigator usually refers to the ultimate silver halide particles of the emulsion, or to the minute particles of metallic silver resulting from the reduction of the halide during development. A complete specification of grain as thus defined is given by stating the apparent diameter of the particles and the relative number of each size present in a given volume or mass of the emulsion. A curve plotted with the number of grains of a given size as ordinates and the grain size as abscissæ values results in a curve of the probability type; the exact shape of which is a function of the particular emulsion considered.

Now, when a case of lesser magnification is considered, such as exists, for instance, in the projection of motion pictures, or in the making of enlargements, the lack of homogeneity is due not to the ultimate grains themselves, but to aggregates of these grains composed of a relatively small number of the ultimate particles. To this type of non-homogeneity the word " graininess " is applied in order that it may be clearly distinguished from the effect produced by the resolution of the individual grains under much higher magnifications. In this paper, therefore, whenever the term " graininess " is used it should be understood as a designation of that effect of inhomogeneity exhibited by the photographic deposits due to the presence of groups or clumps of silver particles. The grainy appearance, which can be observed by the unaided eye, is due to further agglomeration of these aggregates and should properly be referred to as graininess of the second order. It is evident, therefore, that there are three phases in the non-homogeneity of a photographic deposit, (a) graininess due to the existence

of the individual particles of silver, (*b*) graininess due to clumping of these particles, and (*c*) graininess due to the agglomeration of the clumps. It should be understood that these phases are not separated by any distinct line of demarcation, but merge by imperceptible gradations into each other. *Graininess* in reality is a subjective factor, and may be defined as the sensation or impression of non-uniformity in a photographic deposit, produced upon the consciousness of the observer when such a deposit is viewed. This impression is the result not only of the size of the grains of which the deposit is composed, but also the distribution and arrangement in groupings of various kinds.

The graininess of a plate of given performance is dependent on the grain characteristics of the emulsion. The magnitude and distribution of the grains in a given emulsion is determined by various factors operating during its manufacture. The distribution of grains is not subject to positive control; at best it will be only a probability distribution. To secure the lowest graininess in a photo-sensitive material of a given performance with respect to speed, latitude, contrast, and so forth is one of the problems of the emulsion maker. It will be the concern of the plate user to ascertain if any part of the treatment he is likely to give the photographic material received by him from the manufacturer has an influence on graininess, and if this is found to be the case, to determine the optimum condition for the minimizing of graininess. The factors which the plate user has largely under control are the exposure of the plate, the nature of the reducing agent, and other constituents of the developer and their concentration in the developing solution, the temperature and duration of development, and various conditions that enter during the after-treatment of the negative, in washing, fixing, drying, intensification, or reduction and the like.

Experimental inquiries on these points have already been made by various investigators. Schaum [1] found that a variation in the exposure carries with it a corresponding variation in the size and dimensions of the silver grains. M. M. A. and L. Lumiere and A. Seyewetz [2] state that overexposure evidently reduces the size of the grains. They found, moreover, that the grains deposited by the developing agents ordinarily used in practice are of practically constant magnitude, but that two developers, paraphenylenediamine and orthoamidophenol, used under special conditions,

give a grain much finer than that produced by the usual method of development. As to the other constituents of the developer, they found that an excess of alkali or of alkaline bromide appears to produce a very slight increase in the size of the grain. The concentration, temperature, and duration of action of developers appeared to them to have no apparent influence on the size of grains of reduced silver. On the other hand, Wallace [3] states that " the original grain-particles of the silver bromide are by prolonged development considerably enlarged by reason of the formation of group particles, which are relatively enormously increased in size, so that a method of rapid development (provided that the developer is compounded not to give too great a contrast) is the means of obtaining a more definitely uniform deposit of particles, which most nearly approach the size of the original silver bromide. The relative grain size of various deposits was determined by Lumiere and Seyewetz by dissolving off the gelatine coating on the negative in hot water, and after shaking, examining the silver particles under the microscope or by means of photomicrographs. Wallace examined the silver *in situ* by the same means.

Many other investigations on the general subject of grain have been made, but no attempt will be made at this time to give a complete bibliography of this literature. The standpoint from which this subject is approached in the present paper is quite different from that of previous investigators, and the few references given above are mentioned in order to emphasize the difference between the two points of view and also because of the interest attached to a comparison of the results of investigations on " grain " with those of this paper on " graininess."

These investigations of grain while providing valuable information as to the size of the ultimate particles do not yield data adequate for the specification of the magnification to which a given deposit may be subjected without exhibiting an appearance of graininess, nor do they make it possible to classify the various emulsions in relation to their graininess characteristics. In view of the very extensive use of photographic materials for purposes which require subsequent enlargement of the photographic deposit, it seemed highly desirable to develop a method whereby the graininess factor might be measured and specified numerically. Such a method will permit of the determination of the relative merits of various emulsions and the effects of the various steps

in the production of the ultimate result, such as development, fixing, washing, drying, etc.   The only method for the determination of graininess at the time this work was undertaken was entirely qualitative in character.   This consisted of the preparation of a series of prints made at a fixed degree of magnification from the positive under consideration.   These were then examined by a number of observers, and judgments rendered as to the relative graininess of the various prints.   By averaging the individual opinions, final decision as to the proper order of arrangement in the series was obtained.   Such a method while giving some information as to the graininess characteristics is not quantitative and is not at all satisfactory.   Another method suggested and applied to a certain extent in this laboratory consists in placing a mesh grating over the density to be examined and by observing this under a microscope counting the number of groups of grains that fall under several of the openings of the grating.   The average number of groups per unit area was then considered as a specification of the graininess.   There is no reason, however, to suppose that graininess is directly proportional to the number of groups, it being more probable that this subjective impression is some complicated function of other factors such as the size and distribution of the grain aggregates.

The possibility of utilizing the factor designated as Q by Callier [4] was also considered.   This factor is the ratio of the specular to the diffuse density of a photographic deposit, and hence must be some function of the grain characteristics of the deposit.   It is probable, however, that the value of this factor is dependent more largely upon the size of the ultimate particles than upon the distribution of these particles in aggregates and groups of aggregates, and since the preliminary experiments made in an effort to connect Q with graininess did not yield promising results, it was decided to adopt a more direct method for the determination of graininess.

After careful consideration a method based on a principle more closely parallel with the actual conditions existing in the observation of grainy photographic deposits appeared to give greater promise.   The fundamental assumption upon which this method is based is that the graininess of a deposit is directly proportional to the distance at which the appearance of graininess becomes just imperceptible, provided that all other factors upon

which depend the ability of the eye to distinguish lack of homo-
geneity are constant. For instance, consider an enlargement of
a photographic density, the degree of enlargement being such that
the lack of homogeneity (*i.e.*, graininess) is readily apparent
when observed at, let us say, ordinary reading distance (*i.e.*,
30 cm.). Now, if the viewing distance be increased gradually, a
point will finally be reached at which this lack of homogeneity will
disappear and the entire print appear to be of uniform brightness,
free from all visible texture. The distance at which this con-
dition exists may be taken as a numerical measure of the graininess

FIG. 1.
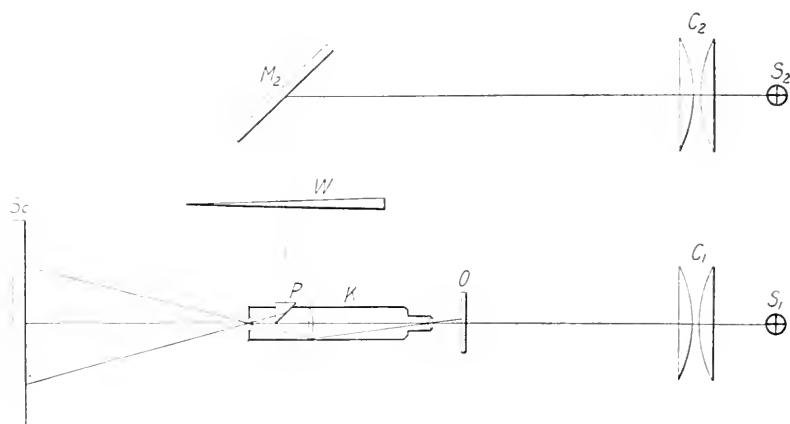
of the enlargement. If another enlargement made to the same
degree of magnification be viewed under precisely similar con-
ditions the distance at which graininess disappears when com-
pared to the distance at which graininess disappeared in the pre-
vious case will provide a numerical specification of the relative
graininess of the two deposits. The determinations made in this
manner would, however, be subject to large errors; the readings
would vary from day to day and be dependent upon the individual
characteristics of the observer.

In order that such a method be satisfactory, it is necessary
to control the conditions of observation so that the results obtained
shall depend only upon the variations in the photographic deposits
considered. It is evident that the distance at which a non-homogen-
eous surface appears to be homogeneous in texture is a function of

the resolving power of the observer's eye, and hence all factors upon which depend this resolving power must be kept constant during observations or the method so arranged that errors due to variations in resolving power may be eliminated. It is thought that in the method developed in this investigation the influence of all variable factors that operate to invalidate the results have been very largely eliminated, and that graininess has been expressed in terms of an easily reproducible standard.

The diagrams shown in Figs. 1 and 2 show the arrangement of the essential parts of the instrument designed and built for the measurement of graininess, Fig. 1 being a side elevation and Fig. 2 a plan view. Light from the source S_1, passes through a

FIG. 2.
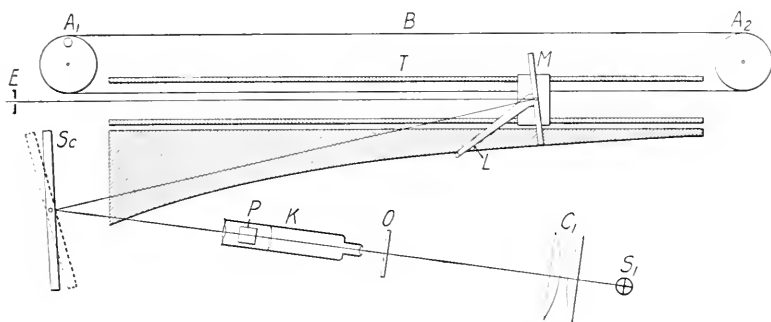
condenser C_1, to the object O, thence through the microscope K, which projects a magnified image of O on the upper half of the diffusely reflecting screen Sc. Light from a companion source S_2 passes through the condenser C_2 and is reflected by the mirror M_2 through a neutral wedge W and into the prism P, by which it is again reflected to the lower half of the screen. The observer places his eye at the artificial pupil E (Fig. 2) and views the image projected on Sc in a mirror M, which may be moved along the track T by means of a belt B passing over the pullies A_1 and A_2, and to which it is attached. A lever L acting on a template maintains the mirror, easily movable about its vertical axis, in such a position that the image of Sc reflected in it is always centrally in the line of vision of the observer.

S_1 and S_2 are 6-volt, 72-watt concentrated tungsten filament electric lamps, connected in series and working from line current

through a variable lampbank resistence. An ammeter indicates the current passing at any moment, and a voltmeter is so arranged that readings may at any time be taken of the voltage at which either of the lamps is working. The condenser C_1 is mounted in a tube with helical thread, and may be easily moved along its axis in such a way as to control the amount of light that falls on O. C_2 is fixed. The object O may be passed before the objective of the microscope by means of a mechanical stage. The micro-

FIG. 3.
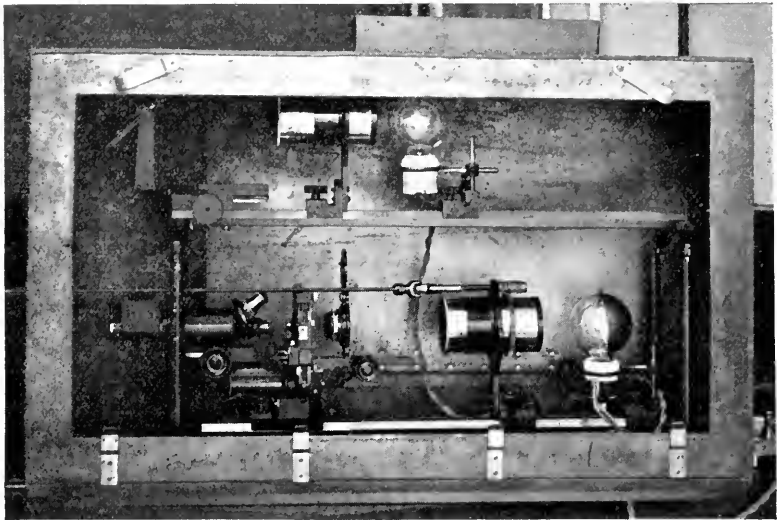
scope is fitted with rotatable nosepiece so that various magnifications may be applied to the object. M_2 is inclinable around a horizontal axis by a screw motion, and may be moved in the direction of the incident beam by means of a rack and pinion. The wedge W is one of the neutral wedges manufactured by the Eastman Kodak Company. The prism P is introduced into a perforation made through the eye-piece and draw-tube and is held accurately in one of the conjugated focal planes of the eye lens by an adjustable clamp, the screen Sc being the other conjugate focal plane. The screen Sc is a magnesium carbonate black whose support is rotatable about a vertical axis, to allow compensation for foreshortening of the image in the mirror. The belt B is a gradu-

ated steel tape, movable by the operator through a crank that actuates the pulley A. The distance separating the mirror M and the observer's eye at E is indicated on the tape by a pointer. All of this various apparatus is inclosed within light-tight and dust-tight housings. A photograph of the projecting system is shown in Fig. 3 and a general view of the complete apparatus in Fig. 4.

Graininess in a photographic deposit is determined by means

FIG. 4.
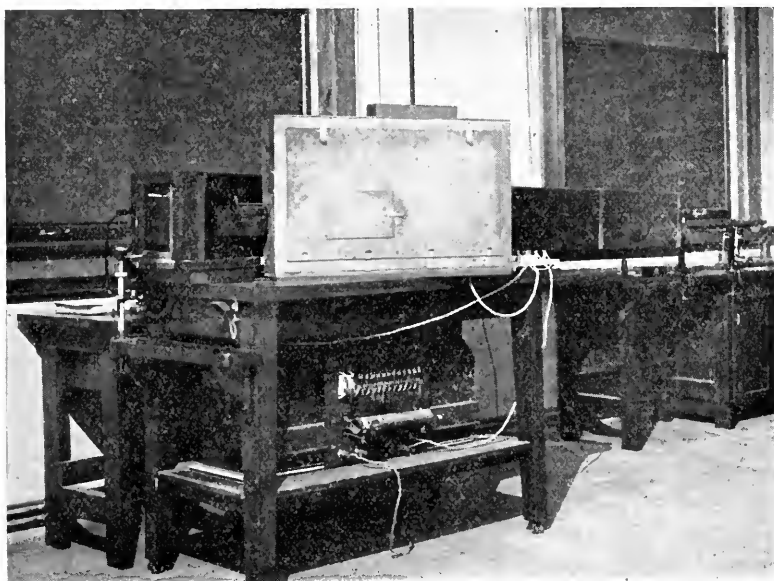
of this apparatus by comparing the distance to which the mirror M must be driven out so that the magnified image of the photographic deposit seen by the observer appears to be reduced to a fixed degree of uniformity, with that required to reduce an object exhibiting a known inhomogeneity to an identical uniformity.

The field of view consists of a circular patch of two parts, the upper one of which is filled by a magnified image of the deposit under consideration and the lower is illuminated to an equal average brightness by a beam of light from the source S_2. Since the prism which serves as a beam splitting device is placed at the focus of the projecting lens a sharp dividing line is obtained

between the two parts of the field. The screen upon which the image is projected is a block of magnesium carbonate, the surface of which is rendered perfectly smooth by scraping with a steel straight edge. The particles of which this block is composed are so small that the surface appears to be absolutely textureless when viewed by the unaided eye. One-half of the field is therefore entirely free from graininess, and serves as a criterion of complete homogeneity with which the magnified image of the photographic deposit may be compared. The brightness of the comparison beam may be controlled by the observer so that at all times a brightness balance between the two halves of the field may be maintained.

The procedure is as follows: The wedge, W, is moved to a position giving an illumination of the comparison field convenient for good visibility. The density to be measured is placed on the stage and its projected image brought to focus on the screen. The brightness of the image field is then photometrically balanced with respect to that of the comparison field by shifting the condenser C_1. The image, of such enlargement as very perceptibly to show graininess at the more proximate positions of the mirror M, is then made apparently to recede from the observer by driving out the mirror. As it moves away the irregularities noticeable in the projected image of the photographic deposit will gradually bend together and at a certain point they will disappear entirely. The position of the pointer on the tape will indicate the distance from the observer's eye at which this has taken place. The photographic density is then removed and an object exhibiting a definite geometrical pattern substituted in its place. The pattern consists of a commercial cross line screen in which a set of parallel black lines drawn at constant intervals from each other is crossed at right angles by a similar set of lines. The lines are ruled 500 per inch and are of a width equal to that of the intervening clear spaces. The geometrical screen is focused upon the diffusing screen, balanced photometrically with the comparison field, and the distance at which the image is reduced to a fixed uniformity read off, exactly as in the case of the photographic density. A comparison of the two sets of readings will give a comparison of the relative graininess of the two objects, and by a simple mathematical process the irregularity of the deposit may be expressed

in terms of a screen of such a number of lines per inch as would be of equivalent graininess.

Let the necessary factors be designated by the following symbols :

D_1 = the minimum distance at which the magnified image of the standard line screen blends into an appearance of complete homogeneity.

D_2 = the corresponding distance for the magnified image of the deposit under consideration.

M_1 = the magnification used in forming the image of the standard line screen.

M_2 = the magnification used in forming the image of the photographic deposit.

N = the number of lines per inch in the standard line screen.

E = the number of lines per inch in a screen of similar geometrical characteristics, which would be equivalent in graininess to the deposit under consideration.

It is well known that within certain limits the relation between the dimension of an object which is just resolvable by the eye and the distance at which resolution is just possible is linear.   That is, the resolving power of the eye may be specified by the magnitude of the angle subtended at the eye by the object considered, this being the case it may be demonstrated that the factors previously defined are related to each other by the following equation :

$$E = N \frac{M_1 D_2}{M_2 D_1}$$

In case $M_1 = M_2$, which is usual in practical work,

$$E = N \frac{D_2}{D_1}$$

The greater the graininess of the deposit the smaller will be the value of E.   Graininess is, therefore, inversely proportional to E, or directly proportional to $\frac{1}{E}$, therefore, G

$$G = c . \frac{1}{E}$$

where c is a constant of proportionality.

For the sake of practical convenience it seemed desirable to adjust the value of c so that the values of graininess (G) should be greater than unity.   After examination of the data obtained from a number of photographic plates, varying over wide limits

in graininess, it was decided to choose arbitrarily a value of 100,000 for c. This results in values of graininess of convenient magnitude for practical work, the values obtained with the group of plates thus far examined lying between 10 and 200. The numerical specification of graininess, therefore, in terms of the standard line screen, the observed distances D_1 and D_2, and the known magnifications M_1 and M_2, is given by

$$ G = 100{,}000 \cdot \frac{M_2 D_1}{N (M_1 D_2)} $$

In making measurements with this apparatus errors may be introduced by the action of causes which determine the objective visibility of the image, by variations in the resolving power of the observer's eye, or by a shifting criterion of the degree of uniformity to which the photographic deposit or the comparison screen is reduced.

The objective visibility of the projected images might be affected by changes in the brightness of these images, due either to variations in the luminosity of the sources following a change in line voltage, or to imperfect photometric balancing of the images of the photographic density and of the line screen, respectively, with the comparison field. Pronounced selectivity in a photographic deposit may occasion difficulty in establishing a correct photometric comparison, but by the introduction of absorption filters in the comparison beam a given color in a photographic deposit may be satisfactorily matched. When making measurements of the line screen with this filter in place another similar filter must, of course, also be introduced into the direct beam. It has been determined that the variation of visibility in the images due either to shifts in line voltage, or to errors in photometric balancing that would ordinarily occur are not of great magnitude.

Another cause that would affect the objective visibility of the image is irregularity in focusing. When using an objective possessing considerable curvature of field, it was found that an average difference of nearly 20 per cent. existed between readings of the half-tone screen taken with the peripheral portion of the field and the central portion of the field respectively, brought accurately to focus on the screen. In order that all readings made in a series of measurements be comparable, it is therefore essential

that a microscopic system giving a perfectly flat field be employed, or if such is not available that the image in every case be carefully focused at some definite zone.

Variation in the readings caused by changes in the resolving power of the observer's eye are also of considerable importance. One factor causing such variation is the changing adaptation level of the eye of the observer. If the measurements be carried out in a darkened room, as they were in the tests reported here, there will be a rapid change in the adaptation level following a transition from daylight to semi-darkness. Experiments showed that these changes were not perceptible in readings of graininess after twenty minutes adaptation from full daylight had been allowed. They also showed that a certain amount of diffuse illumination of a constant low brightness in the room in which the observations were made tended to reduce changes in the adaptation level due to glare, exposure to a certain amount of which is unavoidable. The light sources in the instrument are effectively shaded and the disturbance in the resolving power of the observer's eye incurred by exposure to glare while using the apparatus is so slight as to be negligible. An artificial pupil in the observing eyepiece, E, serves to prevent variations in resolving power due to variations in pupil diameter.

On beginning a series of readings, an initial increase in the distance at which the field is reduced to a fixed uniformity will be observable for a very few minutes, after which the values will begin to fall off as a result of fatigue, continuing to do so until the test is at an end. Since readings on the density being examined and the standard line screen are made alternately, progressive variations in the distance at which complete homogeneity occurs have no effect on the absolute value of the graininess computed from such readings. Supposing perfect adaptation, the rapidity of change in the practice curve will be dependent upon the number of readings taken per unit of time. It was found convenient to take readings at intervals of about twenty seconds. There will, of course, be erratic variations in the practice curve which cannot be associated with any definite physiological or psychological cause.

Since, in the apparatus described, one sensation is compared with another by a threshold method, the readings will be liable to the errors usual in all threshold measurements. It is usual to minimize this error by increasing the number of readings. If in the

present case, however, too great a number of readings be taken, other errors will be introduced due to the constantly shifting form of the practice curve. It was determined by experiment that five consecutive readings on the photographic negative, followed by five readings of the screen, gave an accuracy equal to that attained if ten or twenty readings were taken. If a closer approximation is desired the negative and screen are reread.

All the various disparities in the readings of graininess on a given density, be they due either to changes in the resolving power of the eye of a given observer, or to the individual peculiarities of different observers, are compensated for in the reduction of the readings by the fact that readings of graininess in the density measured are compared with readings of the graininess of a screen of known irregularity and of identical brightness, the two sets of measurements being separated by an interval of such brevity as to preclude marked changes in the form of the practice curve. The effect of regular changes in the form of the practice curve is compensated by a method of interpolation. The effect of irregular changes is dependent upon the rapidity and magnitude of these changes and cannot be eliminated: such changes must, therefore, be reduced as far as is possible. To this end it is essential that all exposure of the observer's eye to glare be avoided, and that the readings be taken in regular sequence and with as little interruption as possible. It is thought that by the observance of these precautions the influence of the variable factors has been so reduced as to bring the accuracy of the method well within the limits usual in sensitometric work.

In order to illustrate the general shape of the practice curve and to determine the precision with which a given graininess value can be established, the data in Table I are presented. A photographic deposit of relatively high graininess was placed in the instrument and the observer after a few minutes of an initial adaptation began a series of readings which continued for approximately one and one-half hours. Five settings of distance were made on the density being examined at intervals of approximately twenty seconds. The line screen was then inserted and another set of five readings made, the average of these two groups of five readings give a determination of D_2 and D_1 respectively. This was continued throughout the period of the test, twenty-four such determinations of both D_1 and D_2 being made in that interval

of time. These values are shown in column D_2 and D_1 of Table I. In column E are given the computed values of that factor as previously defined, the graininess values being entered in column G. In plotting graininess-density curves, it is found more convenient in practice to plot values of the logarithm of graininess rather than the graininess values themselves. These values are shown in the column thus designated. In the column marked ΔG are the deviations of the individual values from the mean of the entire

FIG. 5.
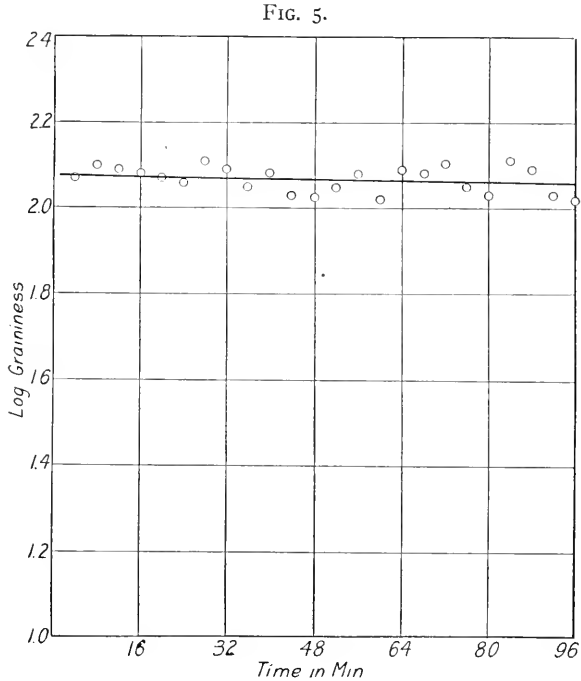
set. At the bottom of the table is shown the mean deviation from the mean, this being 6.5 per cent. From very careful analysis of a large number of results, it is estimated that the values of graininess obtained by this method are subject to a probably error of ±5 per cent. In Fig. 5 the values of log graininess are plotted against the time in minutes from the starting of the series of observation. It will be noted that the first six values lie very close to the straight line, and that as the time increases the scattering of the determinations from its mean becomes more pro-

nounced. This undoubtedly is due to fatigue. However, it will be noted that the curve drawn through the points is practically parallel to the X axis, thus showing there is no tendency to drift either up or down in the determination of the graininess values. In practice such a schedule of procedure is adopted that fatigue effects evident in this particular case are eliminated.

In making readings of graininess it is important to choose a criterion that will be adhered to for all observations. As the image of the plate projected on the screen apparently recedes from the eye, what might be termed a progressive integration of the irregularities of the field takes place. To an unpracticed observer this integration is uniform to completion; the image appears to change from greatest graininess to entire uniformity with perfect regularity. After some observation, however, several more or less distinct stages in the disappearance become evident. With the mirror close to the eye, the primary aggregates are easily resolved. As the mirror is driven out these disappear, and irregular patches are formed. The last are caused by a certain clustering of the aggregates, which makes itself evident by an increase of density in the clusters. On further driving out the mirror, only diffuse markings can be seen, and finally these disappear altogether. These various changes in the appearance of the field are not, however, in any way abrupt, and some difficulty is encountered in determining upon and retaining one definite stage as a criterion. Experiments were made in an endeavor to achieve this end. Four series of readings of a single sensitometric strip containing nine steps, using two criteria at each reading, one of these the initial phase of integration referred to, the other that of the complete disappearance of irregularity in the image. These readings were repeated at separate dates to secure greater accuracy, a total of eighty readings having been taken for each step of the sensitometric strip. It was found by a comparison of these readings that those taken using as a criterion the point marking the first step in the fusing of the image of the photographic deposit, the change from aggregates to clumps, show much greater correspondence with each other than those taken at the disappearance threshold, hence this point was adopted as a criterion for all subsequent readings. The value of a series of readings in an investigation will depend on the accuracy with which this criterion is held from day to day. Fig. 6 shows readings taken on sensito-

metric strips made from the same material (not, however, on the identical strips), the two sets of readings having been separated by an interval of three months.

In the figure referred to, the symbols in full black are those of the first set of readings, and the outline symbols those of the second.   They indicate the order of accuracy with which the

FIG. 6.
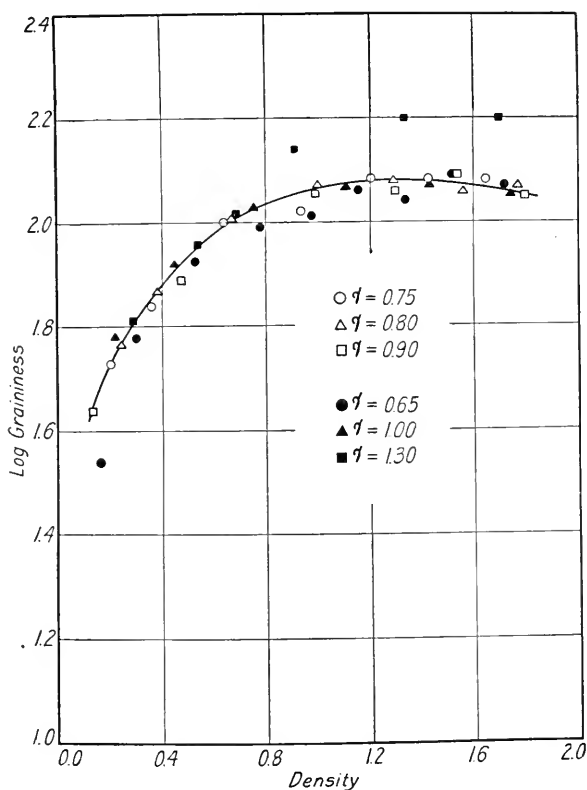
criterion chosen for this work may be held, and also give an idea of the amount of scatter that occurs in the readings.   It may be remarked that the readings of the third strip of the first series appear to indicate an increase of graininess in the higher densities, due to the relatively high gamma, 1.30, to which that particular strip was developed, rather than to normal scatter.

In comparing the performance of various emulsions in respect

to graininess, the strips were exposed in a non-intermittent sensitometer of a type recently described [5] and developed in the developer listed as Pyro No. 1 in the accompanying table, at a temperature of 20° C., fixed in plain hypo, and washed and dried under as constant conditions as could be commanded. In preparing the sensitometric strips to be measured for graininess exceptional care must be exercised to avoid any irregularities in the texture of the gelatine film (such as dust particles or microscopic scratches) other than those due to the graininess of the coating itself.

In the experiments on the action of developers and conditions of development on the graininess characteristics of the finished negative, an emulsion of good speed and constancy was used

FIG. 7.

D:0.23   D:0.38   D:0.67   D:1.00   D:1.29   D:1.56   D:1.77
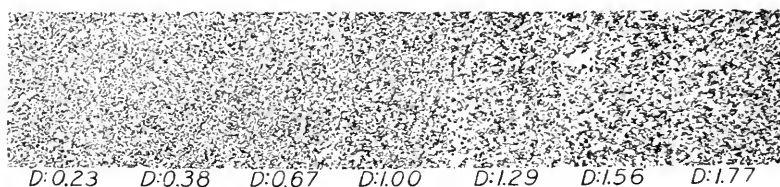
throughout the tests, and all the conditions just mentioned were adhered to unless otherwise mentioned.

The developers used were the following:

Pyro No. 1 is the standard developer used in making sensitometric tests in the laboratory. Pyro No. 2 is a solution of low concentration that had been recommended for the development of high-speed plates, it having been claimed that its use conduces to the production of lower graininess. In hydroquinone Nos. 1, 2, and 3, the concentration of the reducer, of the preservative, and of the restrainer has been maintained constant, whereas the concentration of the accelerator has been progressively increased. Hydroquinone No. 4 is an extensively used process developer. The ferrous oxalate and amidol developers were selected as typical inorganic and organic developers working without alkali. The paraphenylene-diamine developer is one recommended by M. M. A. and L. Lumiere and A. Seyewetz [2] for securing fine grain. These investigators have pointed out that this reducing agent when used without sodium sulphite apparently develops the latent image

through a process very analogous to physical development.   For
the information of those interested the complete developer
formulæ are given following the discussion and the results.

The graininess-density curve represented in Fig. 6, already
alluded to, was obtained from a high-speed plate developed in the

Fig. 8.
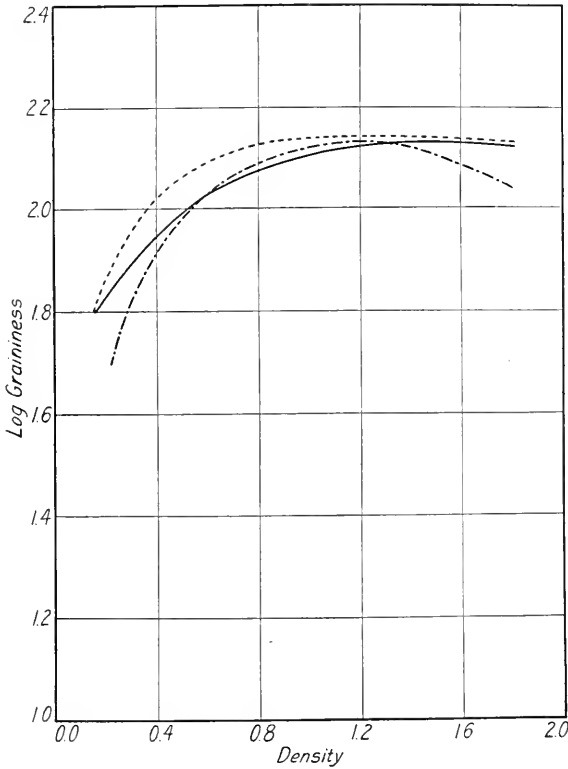
Density

Pyro No. 1 developer listed in the accompanying table.   It shows
that within the range of contrast (gamma) represented, the
graininess-density curves of the various strips show no appre-
ciable mean variation, save in the case of the strip which has
been developed to a gamma of 1.30.   Graininess undoubtedly
varies with gamma in the case of very low or very high gammas,
but the relation of gamma to the graininess-density curve has not
as yet been fully investigated.   The correspondence of the graini-

ness-density curve to what is seen in the negative by the observer is illustrated in Fig. 7, in which prints from negatives given equivalent exposures at the plane normally occupied by the diffusing screen in the graininess apparatus have been printed to approximately uniform densities and arranged in the same order

FIG. 9.
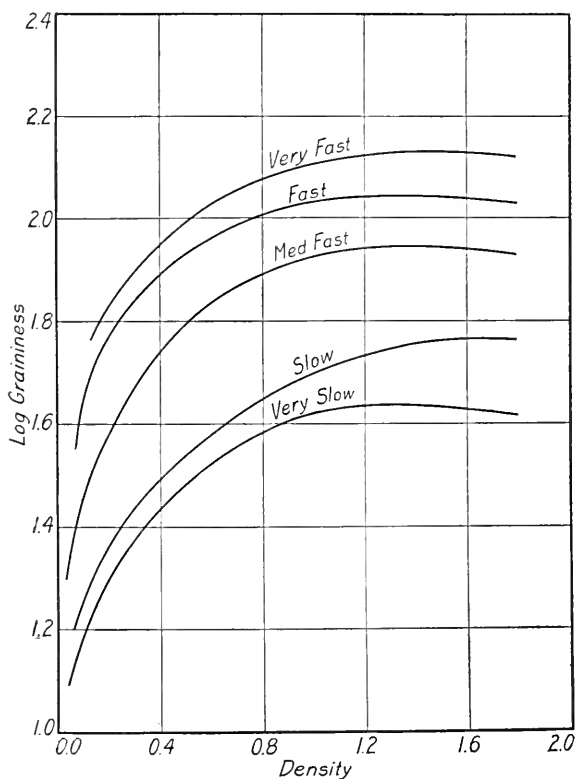
as the steps of the sensitometric strip from which they were taken. The sensitometric strip from which these photomicrographs were made is one of those of which Fig. 6 represents the curve. It therefore affords a direct comparison between the graininess-density curve and the appearance of graininess in the strip.

The shape of the graininess-density curve is constant for a given batch of emulsion, and approximately so for distinct batches of a given emulsion, but shows striking differences in emulsions

of different preparation.   Fig. 7 shows the curves obtained by
the measurement of three very fast emulsions of different manu-
facture.   Curves obtained from readings taken on a series of
plates of one brand, but of different sensitiveness, are shown
in Fig. 9.

A comparison of the performance of the two pyro developers

FIG. 10.
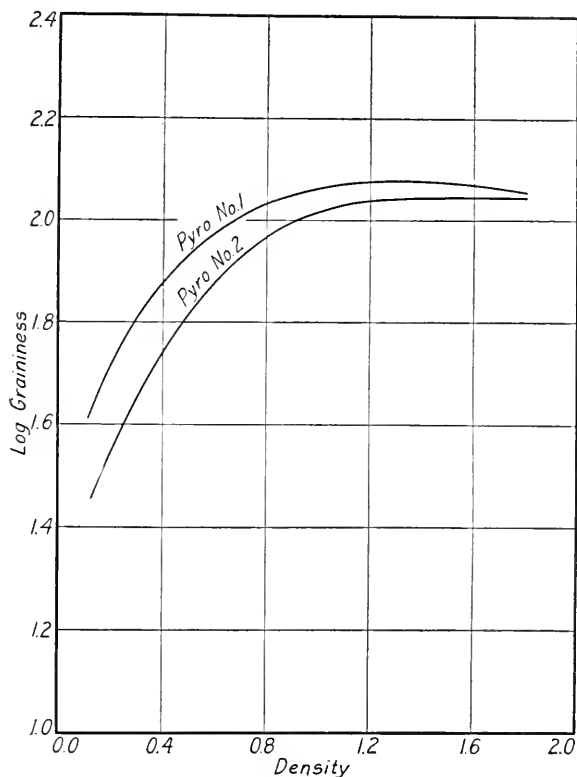
listed, in respect to graininess is given in Fig. 10.   The effect of
modifying the alkalinity of a hydroquinone developer is shown
in Fig. 11.   Fig. 12 represents the curves obtained with the two
alkali-free developers.   Fig. 13 shows curves obtained from strips
developed by means of the paraphenylene-diamine developer listed,
to gammas of 0.25, 0.40 and 0.50.   For comparison, curves ob-
tained from strips developed by Pyro No. 1 to gammas of 0.25
and 1.00 are given.

A test was made of the effect of increasing the concentration of restrainer in the developing solution. Potassium bromide was added to successive portions of Pyro No. 1 developer in quantities such that the concentration of bromide in each succeeding portion would be twice that of the preceding, the concentration of

Fig. 11.
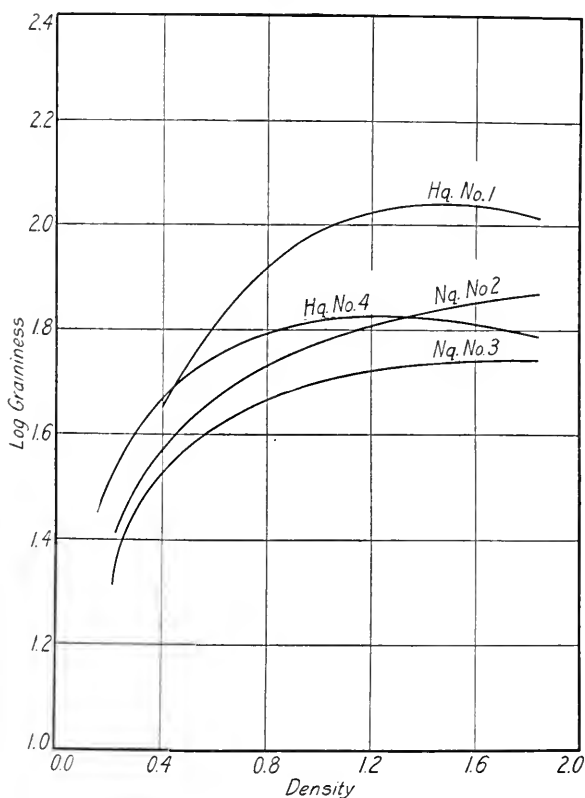
bromide in the series of baths thus increasing logarithmically. Careful measurements failed to show any appreciable effect on the graininess of the strips which had been developed in concentrations of bromide far beyond those which would be used in practical work.

To determine if the temperature of the developing solution has a bearing on graininess, sensitometric strips were developed

in Pyro No. 1 at temperature of 15°, 20°, 25°, and 30° C. No variation in the graininess-density curve was noticed.

It has been thought that an " incipient reticulation " produced in the gelatine film when using an alkaline developer and an acid-fixing bath, especially at higher temperatures, might promote graininess. Strips developed in Pyro No. 1 and also in hydro-

FIG. 12.
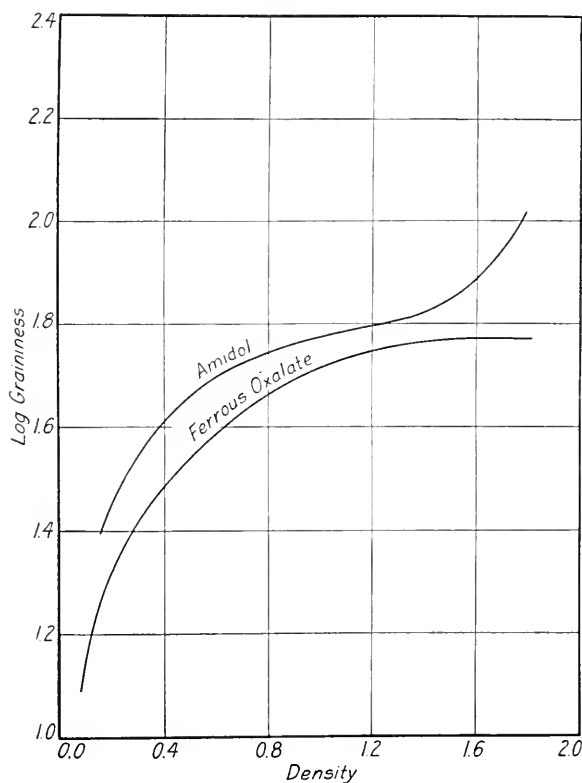
quinone No. 4 developers and fixed in a hypo solution containing no addition, and also in a hypo solution containing acetic acid and potassium alum hardeners, showed no difference in graininess. These tests were carried out at a temperature of 20° C.

An inspection of Fig. 9 will show that the claim that Pyro No. 2 produces lower graininess than other pyro developers is in this case substantiated. In Fig. 10 it will be noticed that an

increase in the concentration of carbonate up to the point of saturation, in the hydroquinone developer used, is in each case followed by a pronounced falling off in graininess. It is also an interesting fact that, though the caustic hydroquinone developer (Hq. No. 4) appears to have a very much more powerful disintegrating action on the gelatine coating of the plate, and

FIG. 13.
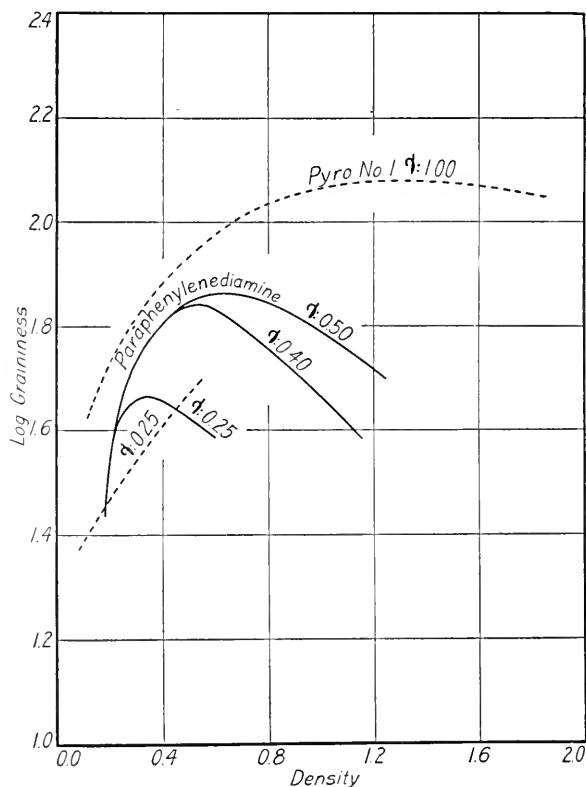
though it develops very much faster than Hq. No. 3 developer, it shows considerably higher graininess than the latter developer.

In the case of the paraphenylene-diamine developer (Fig. 12) it will be observed that the successive curves secured from increasing gammas overlap each other in the lower densities. This is not the case with other developers thus far investigated, the deviation from the normal curve, obtained with very low gammas,

being approximately parallel to the normal curve secured with full development.   The dotted curves in Fig. 12 represent the deviation from the normal in the case of development with Pyro No. 1.   Another notable characteristic of this paraphenylene-diamine developer is the remarkable manner in which the graini-ness falls off in the higher densities.   Unfortunately, this devel-oper calls for about six times the normal exposure in the plate, moreover the contrasts obtained with it are not high, a gamma of 0.67 being obtained with 1.75 hours development, which figure represents approximately the gamma infinity of this developer when used with the plate employed in these experiments.   The deposit, though slightly colored, does not appear to exhibit notice-ably photographic selectivity, and hence a contrasty printing medium must be used to secure satisfactory reproductions.

Except with the spectroscopist, who examines his negatives directly, graininess is generally brought to the notice of the photographer in the reproduction, either in direct enlargement or on the motion-picture screen.   It is assumed in both these cases that the graininess of the printing medium, either paper or cine positive film is negligible in comparison with the graininess of the negative, and consequently that the graininess of the print is substantially that of the negative.   Graininess is usually most apparent in the high lights and lighter half-tones of the reproduc-tion.   Anything that will tend to reduce the graininess in those densities of the negative from which these portions of the repro-duction are prints, will result in an effectively lower graininess in the result.   As the gamma of the negative increases, its higher densities tend more and more to take their position on the upper portions of the graininess-density curve, and since it is the higher densities of the negative from which the high lights and lighter tones of the print are taken, it is these densities which virtually determine the graininess of the print.   This may explain the fact that negatives developed to a high contrast seem to exhibit more grain than negatives developed to a low contrast, although meas-urements show that the graininess-density curves would in the two cases fall on the type curve, a condition that would be filled through a very wide range of gamma.   The same fact may also explain why warm developing solutions are thought to produce grainier negatives.   More chemical fog may develop up under these conditions, and hence to attain a given gamma the plate

must be developed to a higher average density. From a practical standpoint such a negative would be called grainier than a normal negative, because the general increase in density of the negative had brought with it a corresponding general increase in graininess.

Previous investigations have shown that the size of the silver grain is almost independent of the composition of the reducer. The curves that accompany this article show, however, that there is a very appreciable difference in the graininess produced by different developing agents. Graininess then is not altogether a function of grain size, which again emphasizes the distinction between grain and graininess. These results also show that rapidity of development does not necessarily conduce to low graininess. Development goes on faster at higher temperatures without reduction in graininess. An extreme case is presented by paraphenylene-diamine in solution with sodium sulphite alone, which acts very slowly and produces low graininess. An addition of an alkali increases the developing action of this developer enormously, but at the same time increases graininess. The explanation in this case is that the character of development has been changed, presumably from a type of physical development to a typical chemical development. But in chemical development itself, though increasing the concentration of alkali may be said generally to increase the speed of development and at the same time to cause a decrease in graininess, in this case also the graininess does not appear to be a function of the speed of development, but rather of some property intimately related with the specific alkali employed.

DEVELOPER FORMULÆ.

Name	R	A	S	B	
1. Pyro No. 1	10.0	37.5	32.0	0.5	Sodium bisulphite −8.7
2. Pyro No. 2	20.0	25.0	35.0	0.35	Sodium bisulphite −3.0
3. H Q No. 1	5.0	20.0	75.0	1.0	
4. H Q No. 2	5.0	80.0	75.0	1.0	
5. H Q No. 3	5.0	200.0	75.0	1.0	
6. H Q No. 4	12.5	25.0 (NaOH)	0.0	12.5	Sodium bisulphite −25.0
7. Amidol	8.0	0.0	24.0	0.18	
8. Paraphenylenediamine	10.0	0.0	60.0		

The developing formulæ are written in accordance with the system proposed by C. E. K. Mees,[6] the values being grams of the substances indicated per 1000 c.c. of developing solution.

TABLE I.

	D_2	D_1	E	G	Log G	ΔG
1	96	56	857	117	2.068	$-$ 2
2	91	56	795	126	.100	$+$ 7
3	93	58	802	125	.097	$+$ 6
4	90	55	827	121	.083	$+$ 2
5	86	51	843	119	.076	0
6	90	52	863	116	.064	$-$ 3
7	86	57	770	130	.114	$+$11
8	86	53	810	124	.093	$+$ 5
9	87	47	904	111	.045	$-$ 8
10	85	52	820	122	.086	$+$ 3
11	80	43	925	108	.033	$-$11
12	86	46	934	107	.029	$-$12
13	83	47	883	113	.053	$-$ 6
14	89	52	820	122	.086	$+$ 3
15	80	47	945	106	.025	$-$13
16	83	50	800	125	.097	$+$ 6
17	81	51	814	123	.090	$+$ 4
18	83	59	700	143	.155	$+$24
19	80	47	880	114	.060	$-$ 5
20	80	43	930	108	.033	$-$11
21	72	51	764	131	.117	$+$12
22	72	45	800	125	.097	$+$16
23	74	41	930	108	.033	$-$11
24	71	36	960	104	.017	$-$15
Mean	..	..	...	119	.....	7.7
				Mean G (per cent.)		6.5

DEVELOPER No. 9.   FERROUS OXALATE.

Solution A.

Potassium oxalate .... 22 gm.

Water .... 1000 c.c.

Solution B.

Ferrous sulphate .... 270 gm.

Sulphuric acid .... 10 c.c.

Water .... 1000 c.c.

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[2] *Bulletin Societe Française*, 1904, xx, 297 and 422.

[3] *Astrophysical Journal*, 1904, xx, 113.

[4] CALLIER: *Phot. Jour.*, 1909, p. 200.

[5] JOURNAL OF THE FRANKLIN INSTITUTE, 1920, vol. 189, p. 303.

[6] MEES, C. E. K.: *British Journal of Photography*, 1917, p. 535.

EASTMAN KODAK COMPANY,

    ROCHESTER, N. Y.,

        July, 1920.

Application of Photography to Transcription of Original Records.—ARTHUR WORISCHEK of the General Electric Company presents in the *Jour. Ind. Eng. Chem.* (1920, vii, 679) a discussion of the use and methods of photography for making copies of articles in books and periodicals not directly accessible to the research worker. No argument is needed to convince any one of the superiority of such methods to the most careful copying, and it is astonishing that they have not had much wider application than has so far been shown. The question was discussed some years ago in this journal (JOURNAL OF THE FRANKLIN INSTITUTE, 1901, clii, 351; 1914, clxxviii, 743) in which the advantages of the methods were shown, and some practical problems treated. It was there pointed out that the permanence of the paper and of the impression must be carefully considered. The ordinary blue-print has been found to be very durable, but even better is the so-called gum-dichromate method, using a good carbon pigment. In the latter of the above quoted articles, a method of copying without the use of the camera was indicated, being the employing of glass plates coated with luminous paint. When the sheet from which the copy is to be made is written or printed only on one side, this plan is generally applicable and gives good results.

Worischek gives illustrations of several of the newer forms of apparatus for copying purposes, and also mentions an interesting and useful recent application of the film-camera; namely, recording the reading of meters, the camera being operated somewhat on the principle of the motion-picture machine.

<div align="right">H. L.</div>

Fire-damp in the Alsatian Potassium Mines. (*Le Génie Civil,* July 31, 1920.)—In view of our continuing state of war with Germany the great deposits of potassium salts in the eastern part of France are of much interest. One phase of the operation of these mines is the development of fire-damp. At the Theodore mine an explosion due to this cause resulted in the death of eleven workmen. In Alsace the gas is localized in layers of bituminous schist deposited with the strata of potassium salts. A peculiar smell pervades the mines recalling fish oil and also hot mineral oil. Hydrogen sulphide is likewise present as well as a little hydrogen.

Since the normal quantity of dangerous gas is small, the method of working employed by the Germans permitted the use of lamps with open flame except in certain specified conditions. After the French had taken over the operation a pillar was blown up and the roof collapsed. Much fire-damp was set free and an explosion followed with disastrous results. To avoid the recurrence of similar accidents the French Bureau of Mines has prescribed the employment of safety lamps in all the workings. Better ventilation will be provided and a more secure method of supporting the roof will be introduced.

<div align="right">G. F. S.</div>

THE CROSS-ARM WIND-BALANCE.*

BY

DR. A. F. ZAHM.

Bureau of Construction and Repair, U. S. N.

Preface.—When, during the early months of 1918, the new 4′ x 4′ wind-tunnel, at the Washington Navy Yard, was nearing completion, an aerodynamic balance was needed for it that could measure lift, drag and pitching moment, and could be delivered at an early date. The only balance immediately available in America then was one that had recently been made for sale by Mr. C. B. Kirkham, Chief Motor Engineer of the Curtiss Aeroplane and Motor Corporation, from patterns made by that company for its 4′ x 4′ tunnel. The balance had been devised for that company, in 1916, by the present writer, then Chief Research Engineer, and is an adaptation of his former balance used early in 1902. It was reduced to scale drawings by his assistant in the company, Mr. A. P. Thurston, who supervised its construction and made the calibration.

Construction of the Balance.—Fig. 1 shows the external appearance of the instrument as it was assembled, just after delivery, and mounted on the under side of a plank representing the floor of a wind-tunnel.

The balance consists primarily of a hollow vertical main shaft capable of rotating about its own axis and about two coördinate horizontal axes, one normal, the other parallel to the wind direction. This sturdy main shaft is supported in a bronze hub having four split spokes, accurately milled, into which are bolted four steel-weighing beams provided under their tips with knife-edges resting in V blocks, which themselves rest in the bottoms of four iron lugs jutting down from the base casting screwed to the under side of the tunnel. One pair of the V blocks can be raised to carry the whole vibrating system, or lowered to let it rest on the other pair. Thus the main shaft can vibrate either across or along stream, and thereby measure lift or drag on the wind model.

A ratchet arm fixed to the main shaft turns it through any

* Communicated by the Author.

VOL. 190, No. 1139—50   685

desired angle and clamps it to the hub's large flange, having 360 teeth, accurately milled and numbered.

Rotating in ball-bearings in the upper half of the main shaft,

Fig. 1.
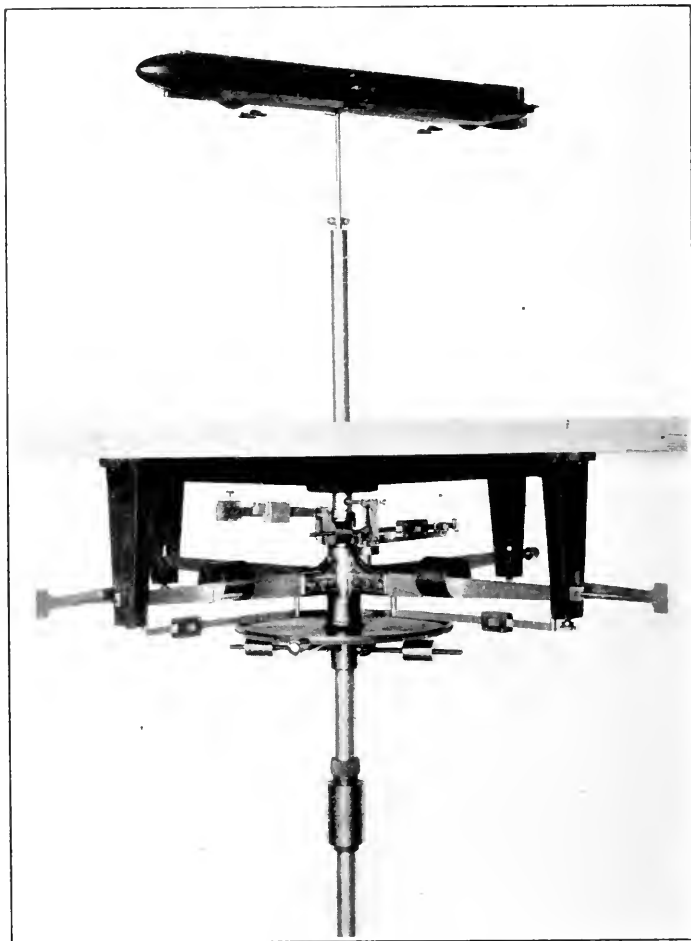
The cross-arm wind-balance supporting a model.

is a light model-holding spindle whose lower end has a horizontal arm engaging the forked vertical arm of a small bell-crank balance, for weighing the wind moment about the spindle axis.

In the upper left corner of the photograph is shown a fourth

weighing beam for vertical forces, but which can be ignored for the present, not yet having been put to use.

Suitable tares are provided for balancing the three weighing beams, and for adjusting their sensibility; also for bringing the centre of gravity of the main shaft and all it carries, including the model, precisely into the vertical axis of rotation, and to a suitable height in the axis. Oil dampers, not shown in the photograph, are added to the ends of the weighing beams, to steady them when necessary.

To ensure that no air shall leak through the tunnel floor where the main shaft enters, this carries an inverted cup dipping into an annular cistern of oil in the hub of the base casting. This casting, which supports the entire balance, is fixed to the underside of the tunnel floor with four supporting screws fitted neatly in elongated slots, so as to admit of orientational adjustment relatively to the wind direction.

A telescopic wind-shield, not shown in the photograph, encases the spindle from the tunnel floor up to within a few inches of the model.

The whole balance and moving weights aggregate about 60 pounds.

Assembly and Adjustment.—While assembling the balance, care is taken to see that the three truss rods joining the ends of the balance arms, and not shown in the photograph, are of such length that the two knife-edge systems are mutually perpendicular. No truss rod spans the weigher's angle between the two graduated beams. Then the instrument is mounted under the tunnel, and its tares are adjusted to ensure equilibrium with the main shaft vertical, whatever its orientation; and the scales for showing deflections are adjusted to read zero for that position. The base casting is next given such orientation that the wind drag on the exposed main shaft, or a drill rod chucked in it, is parallel to the lift knife-edges, and shows no horizontal lift component. This can be done truly to less than $.05°$. Then a long thread attached to the axis of the spindle is stretched parallel to the tunnel walls to see whether it exerts any lift component. In the present installation the zero lift direction for the thread is parallel to the tunnel axis to less than $.05°$.

The distance of the top of the main shaft above either knife-edge system, whatever be the sag of the cross-arms, due to the

nearly 60 pounds weight of the balance, is found by measuring the moment about the knife-edge pair produced by a thread attached to the top of the shaft, and exerting a known force horizontally across the knife-edge direction. The top of the shaft then can be used as a bench mark to find the height of a model above the knife edges. The top of the base casting also can be used as a bench mark, its distance from the knife-edge seats having been measured before the final mounting, by calipering from the top of the casting to a straight edge resting in the V blocks. The distance from the model to either bench mark can be directly measured, and thus the distance from the model to either knife-edge axis can be determined truly to about 0.1 per cent. The knife-edges are about one yard below the axis of the 4' x 4' tunnel.

Graduations and Sensitivity.—The main weighing beams have each two sliding weights, a large and a small one, playing over their respective scales ten inches long, graduated to inches and tenths. The smaller weight has one-tenth the mass of the larger, and measures .001 pound-inch moment when read to one-tenth of its smallest division. By using a lighter weight, and adjusting for fine sensitivity, the balance can be made to indicate an increment of static moment less than .0001 pound-inch, which represents a drag of .000003 lb. applied to the spindle at the axis of the tunnel. This is hardly one per cent. of the smallest measurement the balance is usually required to make.

The single beam for weighing moments about the vertical axis also is graduated in inches and tenths, and carries two sliding weights, the lesser of which measures to .001 pound-inch when the scale is read to one-tenth of a small division.

Original Form.—In the form of balance used by the writer in 1902, in his wind-tunnel, the main shaft could rock along and across stream simultaneously, so that lift and drag could be measured at one time. This was effected by a kind of gimbal support. One pair of cross-arms rested at their tips in knife-edge seats borne by a horizontal ring, which itself rocked about a pair of knife-edge seats square with the other two, and borne by a round base plate mounted on the tunnel. This base plate was circularly graduated and could rotate in a horizontal plane, so as to make the resultant air force on the model perpendicular to the direction of one pair of knife-edges. Since in many cases the air force is horizontal and at a known height, it could thus be

directly determined in magnitude and orientation.   Or, if pre-
ferred, the knife-edges could be set respectively along and across
current, so as to measure the rectangular components of the force,
i.e., the lift and drag.

   This was probably the earliest of the now familiar bell-crank
aerodynamic balances.   Structural drawings of it were fur-
nished to the British Government early in 1905, and a written
description of its simplest form had been communicated to the

FIG. 2.
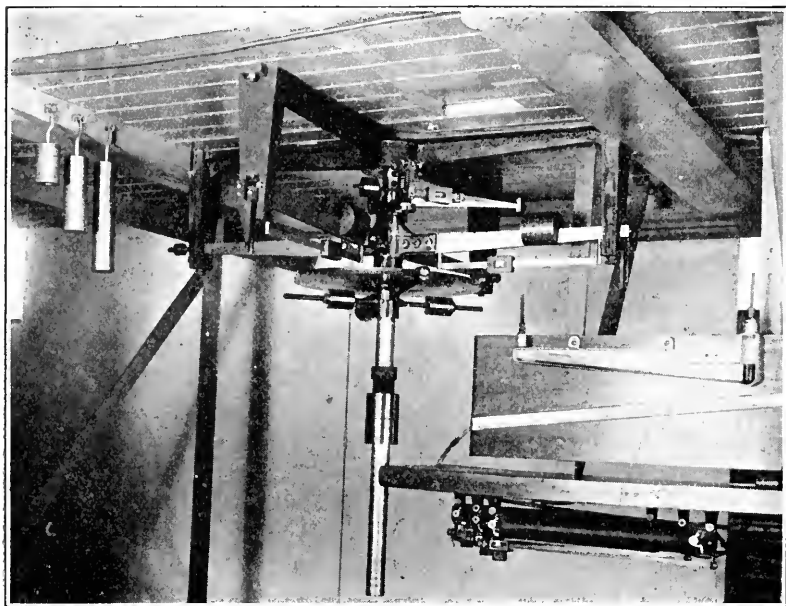
The cross-arm wind-balance attached underneath the wind-tunnel floor.

Pittsburgh meeting of the American Association for the Ad-
vancement of Science, June 30, 1902, in the following words:

   " Among other instruments that we are using may be men-
tioned a universal pressure balance.   This consists of a bell
crank mounted on knife edges above the tunnel, one arm of
which, the horizontal, is graduated and provided with weights,
while the other arm runs vertically down into the tunnel, and
holds the object whose resistance is to be found.   The knife
edges may be set crosswise the tunnel, or lengthwise, or at any

angle. Thus by simply turning the balance, it may be used to measure the lift, drift, or the resultant pressure on the exposed body at any angle whatever. The instrument is graduated to tenths of a gramme, and is strong enough to measure several thousand grammes."

Experience with the Present Balance.—In its present form the cross-arm balance has proved satisfactory in point of permanency of adjustment and precision of measurement. The mounting directly underneath the floor of the tunnel is practicable when the latter is made of seasoned wood and is reasonably free from jarring. The cast-iron base could be made to rotate in a horizontal ring, if desired, but little want for this has been felt. If more were required than the measurement of forces and moments, other attachments could be added which are too well known to need description here.

Accompanying Equipment.—Fig. 2 shows the balance screwed to the under side of the 4' x 4' wind-tunnel, and in its working environment. The air current in the tunnel is maintained by a four-blade suction screw chain-driven from an electric motor on the floor of the laboratory. The speed of the motor, and hence of the air flow, can be held steady by a sliding rheostat under the shelf on the right of the balance. Above this shelf, or writing table, are seen two inclined alcohol manometers. One is permanently connected to a fine hole in the side of the tunnel, and, after calibration, is used to indicate the speed of the air; the other is connected to a standard Pitot tube, temporarily placed at the axis of the tunnel, to calibrate the permanent speed indicator just described. With this equipment a single observer can hold the airstream constant at any speed up to more than 60 miles an hour, and make accurate readings of the wind velocity and of the component forces and moment of the wind on the aerodynamic model.

U. S. ARMY SEARCHLIGHTS.* †

BY

CHESTER LICHTENBERG.

Captain of Engineers, U. S. Army.   Member of the Institute.

FINDERS.

44. The range of searchlights depends in a great measure upon the relative size of the target which is being sought. It has been found that if the target can be magnified in any way the range of the searchlight can be increased. This has led to investigations and developments of certain searchlight target finders. The devices are essentially telescopes, but so proportioned as to be particularly suitable for night work and for distant targets which are relatively small in size and which present but small contrast against their background. Searchlight target finders must, of necessity, be of the Galilean type. Prisms intercept too much of the light energy and therefore have been excluded. It is believed that these target finders will be most suitable if they have a magnifying power of from four to five times and a field of 9 degrees or greater.

OBSERVER'S POSITION.

45. The relative positions of searchlight, target and observer are of extreme importance in the rapid detection of a target. It has been found that, particularly with high-intensity arc searchlights, there is a minimum distance that the observer can be near the searchlight and see a target. . This is due to the fact that these types of searchlights, particularly when equipped with front doors, have a cone of highly illuminated air particles in their immediate neighborhood. This cone obscures the vision of an observer close to them, so much so that he can scarcely see more than a few hundred yards in the direction of the beam. Experiments made with a high-intensity searchlight and with the observers set out on a base line parallel with the searchlight trunnions gave very interesting results. An airplane was used as a target. It flew through the beam at elevations of 3000 feet to 5000 feet and at ranges of two to four miles. The percentage of times that it could be seen by each of the observers along the

* Communicated by the Author.
† Concluded from page 542, Vol. 190, October, 1920.

base line was recorded on a number of successive nights. The results are shown in the graph in Fig. 34.

46. In addition to choosing proper location for an observer, it is necessary to suitably shield the observer from stray light. It has been found that the pupil of the eye is very sensitive, particularly at low illuminations. It has been found necessary, therefore, for accurate searchlight determinations to exclude from the observer's eye all light excepting that which returns to him from the target and such light as he cannot avoid receiving from the sky. This is done by providing observers with hoods similar to those provided with the old-time stereoscopes. In place of the

FIG. 34.
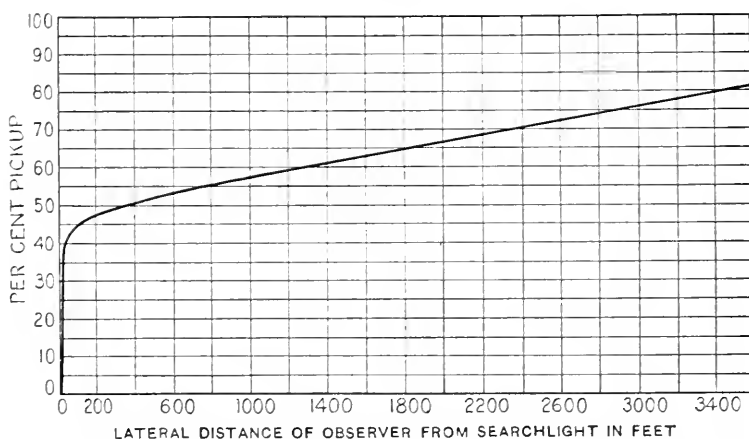
Graph illustrating relative ability of observers stationed in line with the trunnions of a search-light to pick up airplanes in the beam of the searchlight.

lenses, tubes about one inch in diameter and about fourteen inches long are provided. The hoods have the face portion trimmed with black velvet so as to make close contact between the face of the observer and the edge of the hood and thus exclude all extraneous light. The entire equipment does not weigh over one pound and is strapped to the head of an observer by an elastic band. He is thus permitted to gaze along the searchlight beam and in the direction of it, and his vision is restricted to within two or three times the width of the searchlight beam. This scheme has been tried with eminent success and has proven unusually adaptable for field service.

POWER UNITS.

47. Mobile searchlight power units have been the subject of a great deal of study. The entrance of the United States into the war found the Army equipped with only a few mobile power units. Eight of these consisted of 15-kw., 125-volt, direct-current, gasoline-electric sets, each mounted on a 3½-ton F. W. D. truck. One of these sets is shown in Fig. 35. It is relatively mobile, but difficulty was found in driving it through heavy sand and through certain bad roads. It proved, however,

Fig. 35.
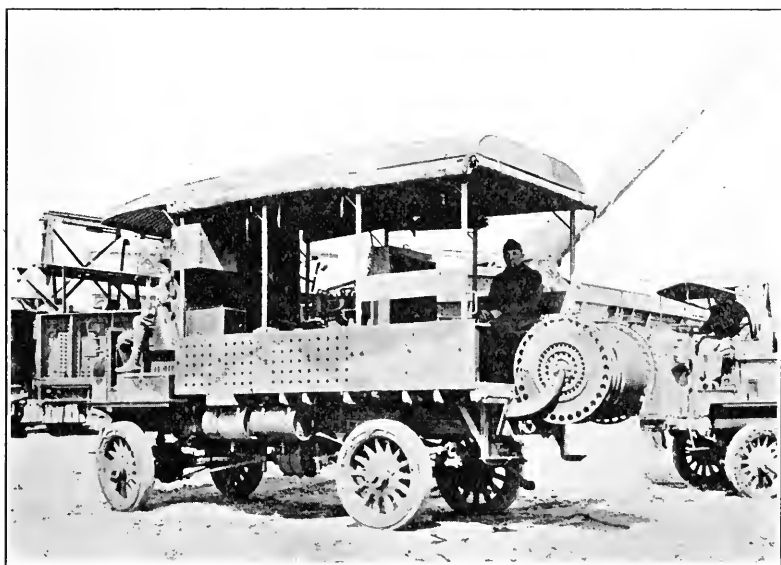
Fifteen kilowatts, 125 volt gasoline-electric generating set, mounted on 3½ ton gasoline driven truck and illustrating an early design of mobile power plant.

to be the most useful power plant of its kind. Nevertheless, there was one objection to it. It required an extra lorry to carry it around and thus meant twice as much equipment as though the engine for driving the lorry was used for driving the electric generator. Another mobile power unit is shown in Fig. 4. It was an attempt to place stationary gasoline-electric generating sets in service with the mobile forces. One of the standard 125-volt 25-kw. sets used for coast-defense fortifications was placed on a standard 3½-ton trailer. The unit was mobile but only relatively so. It could be moved easily over hard roads,

but only with difficulty over bad roads. It could not be moved at
a speed to exceed about five miles per hour. Besides, it had to
be propped into place when the generating set was operative.

FIG. 36.

Five kilowatt gasoline-electric generating set, mounted on artillery limber and intended for
being drawn by horses or mules.

The result was a rather unwieldy equipment which did not prove
successful under field conditions.

48. Still another type of portable searchlight power unit is

shown in Fig. 36.   It consists of a 5-kw., 60-volt, direct-current generator, direct connected to a Winton four-cylinder gas engine, the combination being mounted on a standard artillery limber. This unit formed one-half of a searchlight equipment, the other half being shown in Fig. 48.   It proved successful within certain narrow limits, but on account of being horse-drawn and also on account of its relatively small capacity, it did not prove successful under field service conditions.

Fig. 37.

1917 design of mobile searchlight power unit, typifying the equipment first furnished to the American Expeditionary Forces in France.

49. The early specifications received from the A. E. F. indicated the need for a mobile searchlight power unit of relatively simple design, having at the same time sufficient cargo capacity, in the form of a lorry body, to permit carrying the searchlight and auxiliaries on the same chassis.   The first attempt at meeting these specifications is shown in Figs. 37 and 38.   These illustrate a standard Engineer Department 5½-ton Mack cargo truck with a 15-kw., 125-volt, direct-current generator, placed on an extension of the engine crank shaft.   The cargo body is provided with a cable reel and a 36-inch high-intensity arc, drum-type

searchlight on a wheeled mount. Underneath the cargo body is located a series rheostat for adjusting the current to the searchlight, and a switchboard for regulating the generator. One hundred and eighty of these units were built. Thirty of them were in service with the First and Second Field Armies, A. E. F., in France at the time the November 11, 1918, armistice was signed. A quantity of them were in transit, and the balance were ready

FIG. 38.
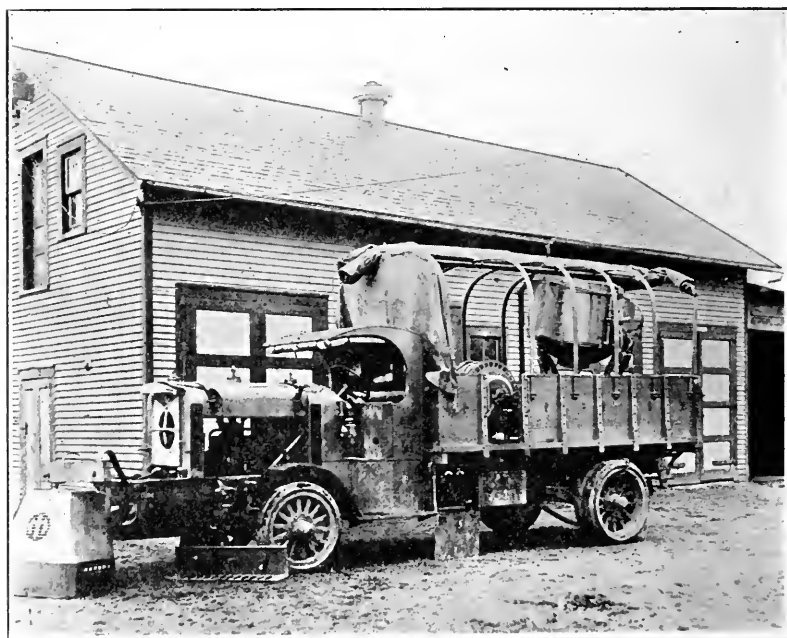
1917 design of mobile searchlight power unit, showing generator, engine, switchboard, cable reel and 36-inch, 150 ampere, high intensity arc, wheeled barrel searchlight.

for shipment when water transportation cargo space should be made available. These units proved relatively successful on hard roads or on dirt roads with sufficient bottom to withstand their weight. They had a maximum speed of twelve miles per hour. They could carry the entire equipment of one searchlight section. They were self-contained, and, in so far as their design limits permitted, exceptionally well performed the functions of a searchlight power unit.

50. Early experience with the 5½-ton searchlight power unit

previously described showed that it was not quite mobile enough for certain field army conditions. Speed was a necessity. Relative lightness was essential. Besides, the development of the open-type searchlight reduced the weight of this portion of the equipment by over 50 per cent. The result was the possibility of using some form of standard motor car or light motor truck with suitable body. The first attempt to meet this condition is shown in Fig. 39. Here a standard 145-inch wheel base Cadillac chassis

Fig. 39.
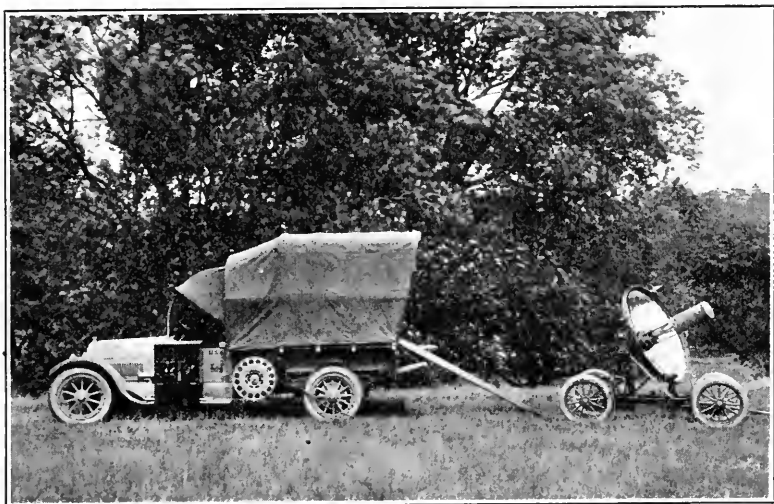
1918 design of mobile searchlight power unit, showing switchboard, cable and 60-inch, 200 ampere, medium intensity arc, open type searchlight.

and engine were equipped with a generator located on the propeller shaft and with a special body for carrying the searchlight and crew. The generator location is shown in Fig. 40. The armature has a hollow shaft. The propeller shaft is run through this. The generator armature is coupled to the propeller shaft by means of a clutch. This is so arranged that the propeller shaft may be connected either to the generator or to the differential and thus the engine used to drive either the generator or the traction wheels. This form of unit reduced the total weight of the power unit and lorry from 14,000 pounds to 6000 pounds. The design was so happily selected that spare parts for it were

readily obtainable at all Motor Transport Depots of the A. E. F., since Cadillac touring cars had been standardized for certain passenger vehicle service in the A. E. F. The equipment with the searchlight in place on the body, but with the bows and canvas cover removed is shown in Fig. 41. In this position, the search-light can easily be operated and can be used for ordinary field searchlight service. The development of this equipment marked a very big advance in the development of searchlight power units, especially and in *mobile* power units particularly.

51. Contemporaneously with the development of the equip-ment just described, an attempt was made to convert a medium

FIG. 40.
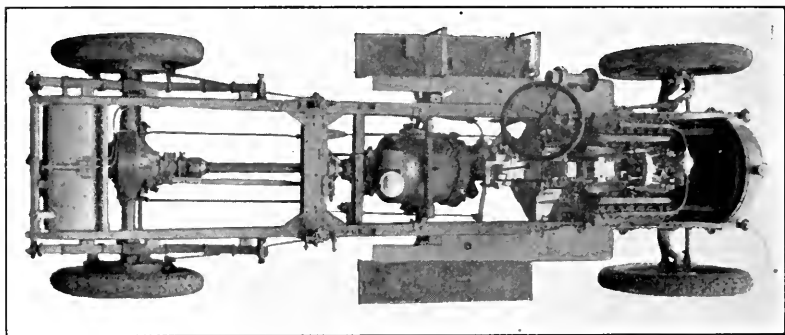
Top view of chassis of 1918 design of mobile searchlight power unit, showing location of 21 kilowatt, 105 volt generator on propeller shaft. The governor is shown to the left of and just below the generator name plate. Hand holes for increasing ventilation are shown just back of the gear shift. The chassis is a standard 145-inch wheel base Cadillac design.

capacity truck into a mobile searchlight power unit. For this purpose, a 2½-ton standard truck chassis was equipped with a 5½-ton standard truck engine, the whole being mounted on pneu-matic running gear. A special body was provided and the search-light mounted thereon. The generator was mounted on the pro-peller shaft in much the same manner as the unit shown in Fig. 40, excepting that the generator armature was keyed to the propeller shaft. A view of an experimental unit of this type is shown in Fig. 42. It was not successful on account of certain limits of design which had been anticipated. It indicated certain possi-bilities, however, which might be utilized in future designs.

52. The success of the searchlight power unit design having the generator placed on the propeller shaft was marked. Before

FIG. 41.
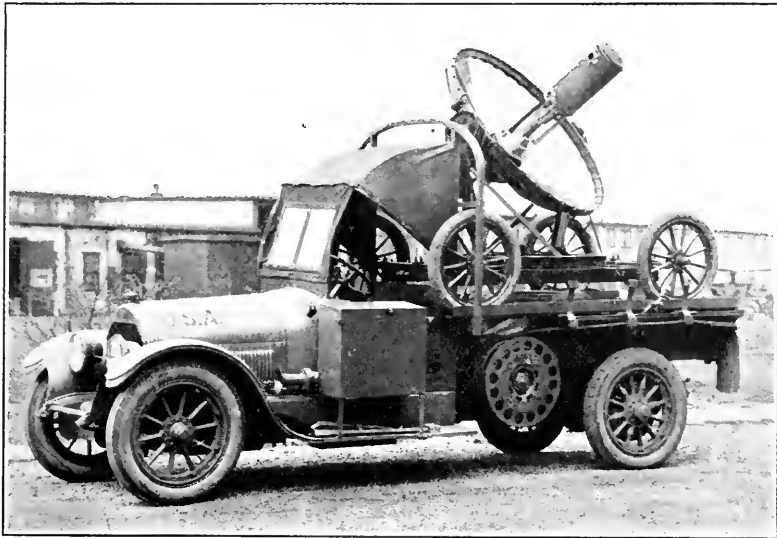
View of 1918 design of mobile searchlight power unit and open type searchlight, mounted ready for immediate service.

FIG. 42.
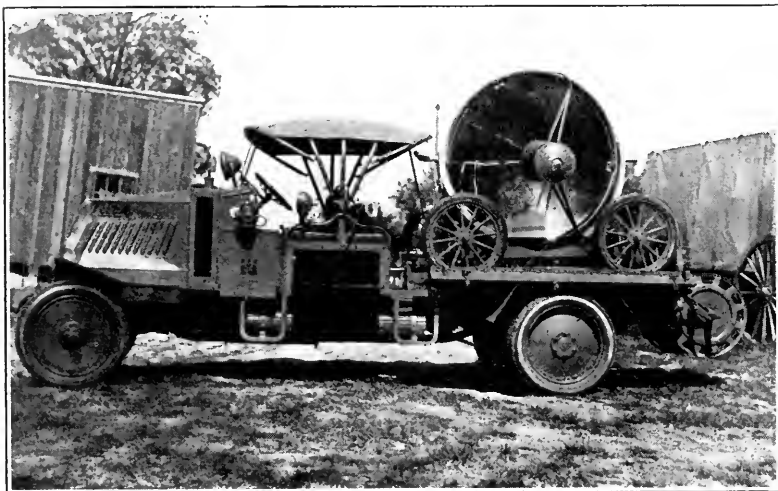
Experimental design of mobile searchlight power unit, with open type searchlight, illustrating the adaptation of standard motor truck equipment for searchlight power unit service.

the completion of the first sample, ninety units similar to those shown in Fig. 39 were ordered. These were brought through with great rapidity, since the chassis and generator were standard and the other parts were relatively simple to construct. One of these units is shown in service with the Second Field Army, A. E. F., in Fig. 43.

53. The searchlight power unit development took a definite form in the fall of 1918. Designs were prepared for 6.5-kw. units and 50-kw. units. An outline drawing of the 6.5-kw. size is

FIG. 43.
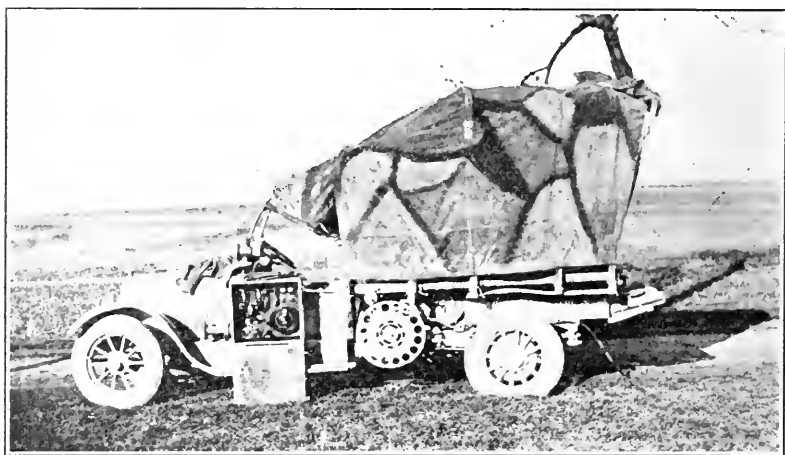
1918 design of searchlight power unit, photographed in the lines of the 2nd Field Army, A. E. F., in France.

shown in Fig. 44. A photograph of the 50-kw. size is shown in Fig. 45.

54. A still further extension of searchlight power unit design was made during the war. It consisted in the installation of two standard 25-kw., 115-volt, stationary gasoline-electric generating sets in a box car. The car axles were provided with electric motors, so that the car could be self-propelled. A sample of this design is shown in Fig. 46. It operated successfully as a power unit and tractor.

55. The essential features of searchlight power units of the mobile type are relatively simple. The engine is one of the principal elements. It must be sufficiently large to drive a generator

Fig. 44.
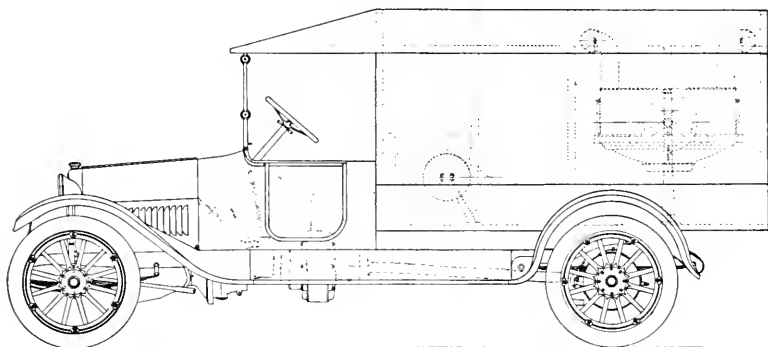
1919 design of 6.5 kilowatt mobile searchlight power unit, illustrating generator on propeller shaft, cable reel and 30-inch open type searchlight. It carries a crew of four men.

Fig. 45.
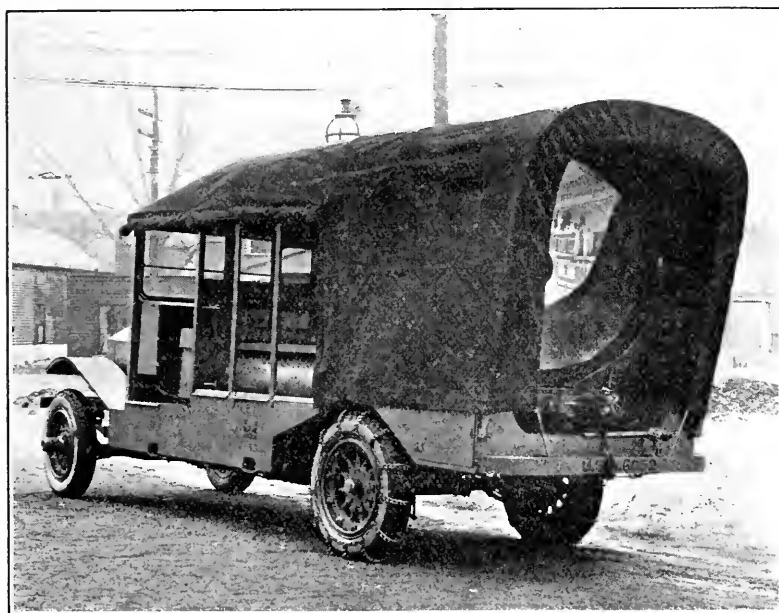
1919 design of 50 kilowatt mobile searchlight power unit. It carries a crew of twelve men with all of their auxiliaries, a 60-inch, 500 ampere open type searchlight and 500 feet of cable.

for supplying power to a searchlight. It must, at the same time, have such characteristics that it will not fail under the duties required of a searchlight generator. For example, when the unit is started, the generator will run at no load. Suddenly the searchlight arc will be started. This means that from four to five times full load is momentarily thrown on the generator. Under these conditions, the engine must maintain the speed of the generator practically constant. It must not permit the generator

FIG. 46.
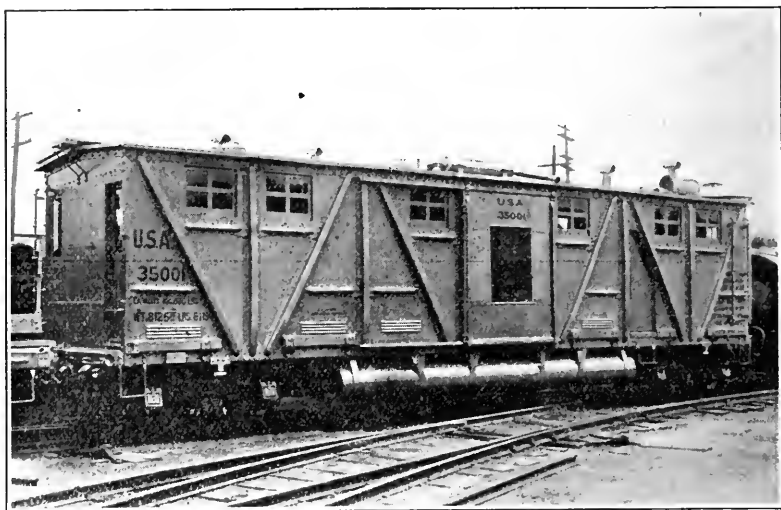
1917 design of mobile searchlight power unit, consisting of two standard 125 volt, 25 kilowatt gasoline generating electric sets, mounted in standard box car, specially equipped with electric motors on the wheel axles.

speed to drop down else the voltage will drop and the arc will be extinguished. This means an engine having a torque characteristic of such shape that doubling or tripling the load momentarily will not appreciably alter its speed.

56. The second important characteristic of a searchlight power unit is its radiator. This must be of such design and construction as to permit operating the engine at about one-half to two-thirds of its normal output, when the power unit is stationary in space. It must also be able to sufficiently cool the engine when the power unit is located at high altitudes as well as at low altitudes and in the extreme conditions of summer in near-tropical

countries, as well as in the summer in temperate countries. It means, besides, a radiator of standard construction so as to reduce the number of special features or parts required. Another essential part of a searchlight power unit is the running gear. This must, of necessity, be pneumatic, since the power unit carries relatively delicate apparatus which must be moved over the road at maximum speed up to 40 or 45 miles per hour. Besides, the unit is required to go through relatively bad roads, sometimes even across ploughed fields and swamps, and for these conditions pneumatic running gear is unexcelled.

57. The chassis of a searchlight power unit is relatively unimportant. To be sure, it is best to have a strong enough one, but so far no difficulty has been experienced in adapting for searchlight power unit service any one of the standard chassis frames which are on the market.

58. Searchlight power unit bodies are relatively special. They are required to carry a searchlight, several hundred feet of cable, 12 to 14 or 15 men with all their paraphernalia, so that they may subsist themselves and operate their unit in the field for about six- or seven-day periods. It has been found that the complete live load on a power unit is about 7000 pounds, so that it can readily be seen why it is necessary to have a relatively large lorry chassis for searchlight power unit service.

TOWERS.

59. Certain applications of searchlights required them to illuminate targets on the earth's surface at ranges of 12,000 to 15,000 yards. Owing to the curvature of the earth's surface, it is necessary that the searchlights for this service be mounted from 40 feet to 60 feet or even 100 feet above sea level. In certain localities advantage is taken of the natural contour of the earth's surface and the searchlights are mounted on elevated points in the landscape. In many places, however, the contour of the country is such as to prevent installation in suitable natural elevated positions. For these places, various forms of towers have been developed for the mounting of searchlights.

60. Searchlight tower mounts may be roughly divided into two classes. First, mounts fixed in position. Second, mounts mobile. The fixed searchlight tower mounts are rapidly becoming obsolete and for the past few years most of the inventive

talent has been concentrated on the development of mobile search-light towers and tower mounts. One of the earliest of these is shown in Fig. 47. This illustrates a 36-inch medium intensity barrel type of searchlight mounted on an extensible tower built after the Bascule bridge idea. The entire equipment is carried on a 3½-ton lorry. By means of the tower, the searchlight can be elevated 20 feet above the surrounding terrain. The equip-

Fig. 47.
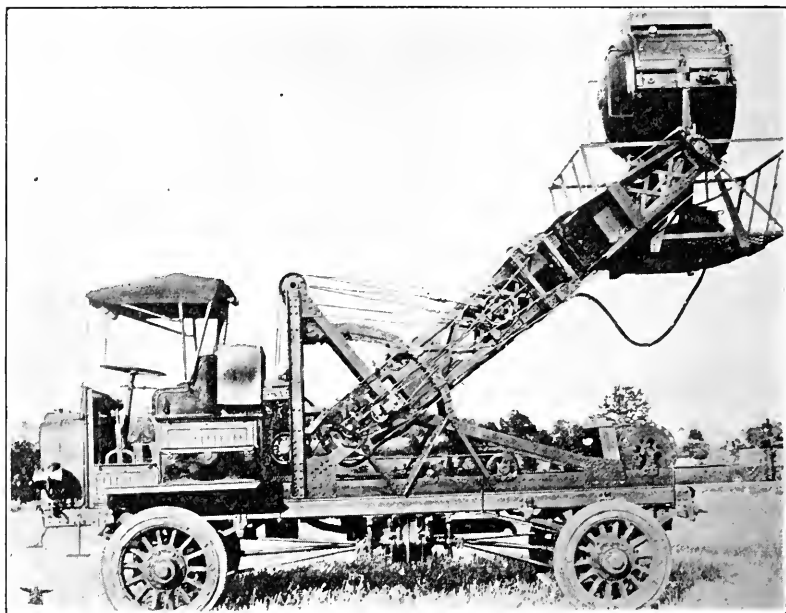
Early design of mobile searchlight tower unit. The tower has a lift of 20 feet and carries a 36-inch, 110 ampere, medium intensity arc, barrel type of searchlight. It is mounted on a 3½ ton truck.

ment was relatively heavy and could only be operated on good roads or ordinary roads. It could not be easily operated cross country or in the fields. Besides, it required a second truck or lorry for carrying the power unit (Fig. 35). Eight of these equipments were used during operations on the Mexican border in 1917, and, so far as their limits permitted, were successful. Experience with them indicated, however, the need for more mobile and more powerful field searchlights on towers. The next attempt at a solution of the problem is shown in Fig. 48.

This illustrates a 24-inch high-intensity arc searchlight mounted on a 16-foot extensible tower. The equipment is placed on a standard artillery gun carriage which, together with the limber shown in Fig. 36, constitutes a complete mobile searchlight unit. The equipment is horse drawn and designed for maximum speed

Fig. 48.
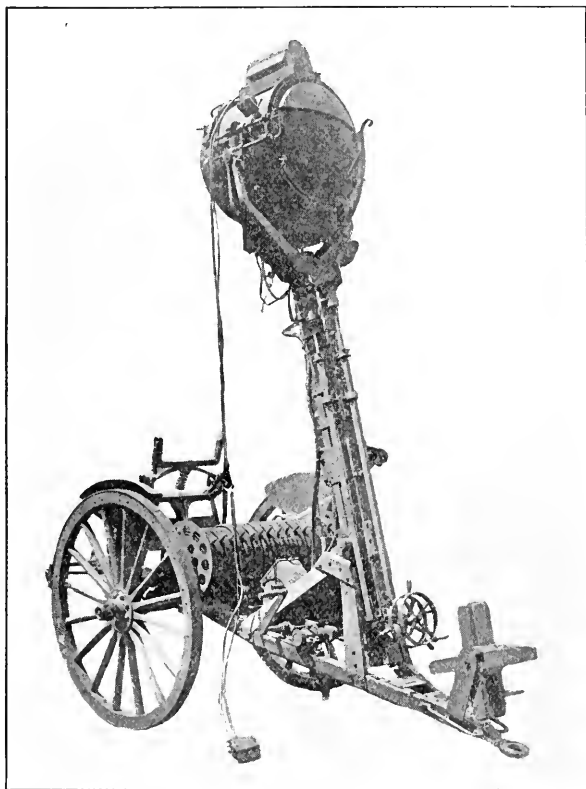
1917 design of tower equipment for a mobile army. It has a 24-inch, 75 ampere high intensity arc searchlight. It is mounted on a mast fixed on an artillery gun carriage, and so arranged that the searchlight may be raised 16 feet above the surrounding terrain.

not to exceed five miles per hour. Eight of these units were sent to France with the First Engineer Train in July, 1918, and within certain limits functioned successfully with the A. E. F. in France. It was found, however, that field searchlights were unsuccessful in trench warfare and the 24-inch searchlights were later dismounted from the towers and used in emplacements.

61. Further developments indicated the necessity for larger mobile searchlights on towers. To meet this situation, a modified form of hinged and counter-weighted tower was designed. It is shown in Fig. 49. It is mounted on a standard railway flat car. It carries a 60-inch coast-defense design, barrel-type, high-intensity arc searchlight. By means of the tower this searchlight can be raised so that its arc is 33 feet above the top of the track rails. This equipment, together with the portable searchlight

FIG. 49.
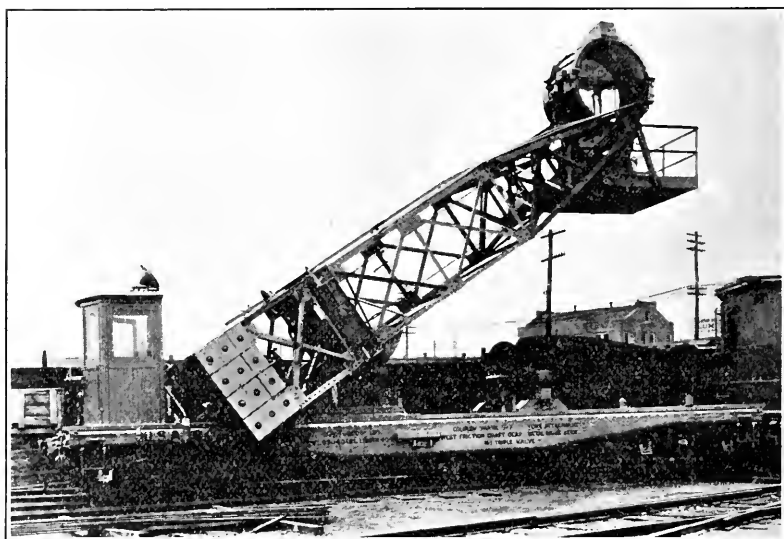
1918 design of hinged searchlight tower mounted on standard steel flat car. The tower carries a 60-inch, 150 ampere high intensity arc searchlight which can be elevated 33 feet above the surrounding terrain.

power unit shown in Fig. 46, represented a complete portable searchlight tower and power unit. It was limited in its activity, however, to points where standard gauge railway track was available. It was self-propelled at speeds up to ten miles per hour. It weighed, complete, 88 tons.

62. Extreme mobility, however, seemed to be the underlying principle in coast-defense operations, as well as in field operations. For this reason it was deemed essential to design a mobile searchlight tower which could move anywheres. A very intensive study was made of the situation, and, based on a careful survey,

the equipment shown in Fig. 50 was designed and is now being built. It consists essentially of a very special searchlight tower mount, carrying a rectangular extensible tower on top of which is mounted a 60-inch high-intensity arc, open-type searchlight. The tower mount has a 125-hp. gasoline engine. It is also provided with an endless track, on which the mount moves over rubber-tired wheels. The mount carries a 50-kw., 100-volt, dc generator chain driven from the engine, which ordinarily drives the mount. The tower is vertically extensible, being drawn into position and lowered from position by a cable hoist operated by an electric motor. The searchlight is connected to the top section. When the tower is collapsed, the searchlight is enclosed inside of the sections, and when the upper part of the tower is drawn in, the sections are closed in similar to a house with a roof. This equipment, it is estimated, will weigh, complete, twenty tons. It will hoist the searchlight to such an elevation that its arc will be 60 feet above the surrounding terrain. It will travel at a maximum speed of twenty miles per hour when the track is removed and at a maximum speed of ten miles per hour with the track in place. It can negotiate any kind of a road and can even run through a swamp with water not over three feet deep. It will climb a 75 per cent. grade with the tower nested, and will undoubtedly prove very successful for coast-defense applications.

CHARACTERISTICS.

63. The characteristics of searchlights are difficult to determine. It is relatively easy to measure the amount of illumination of the source of light in a searchlight. It is difficult, however, to determine how much of this light will reach a distant target. This is because the atmosphere between the searchlight and the target has a preponderating influence on the amount of light transmitted. So it is necessary, in studying searchlights, to take into account not only the principal features of the searchlight itself, but also the energy absorbing characteristics of the medium through which the light is being projected.

64. Sources of light possess two general characteristics. One is their total amount of illumination, the other is their color or the distribution of their radiant energy in the spectrum. The total amount of illumination of a source is determined roughly

FIG. 50.
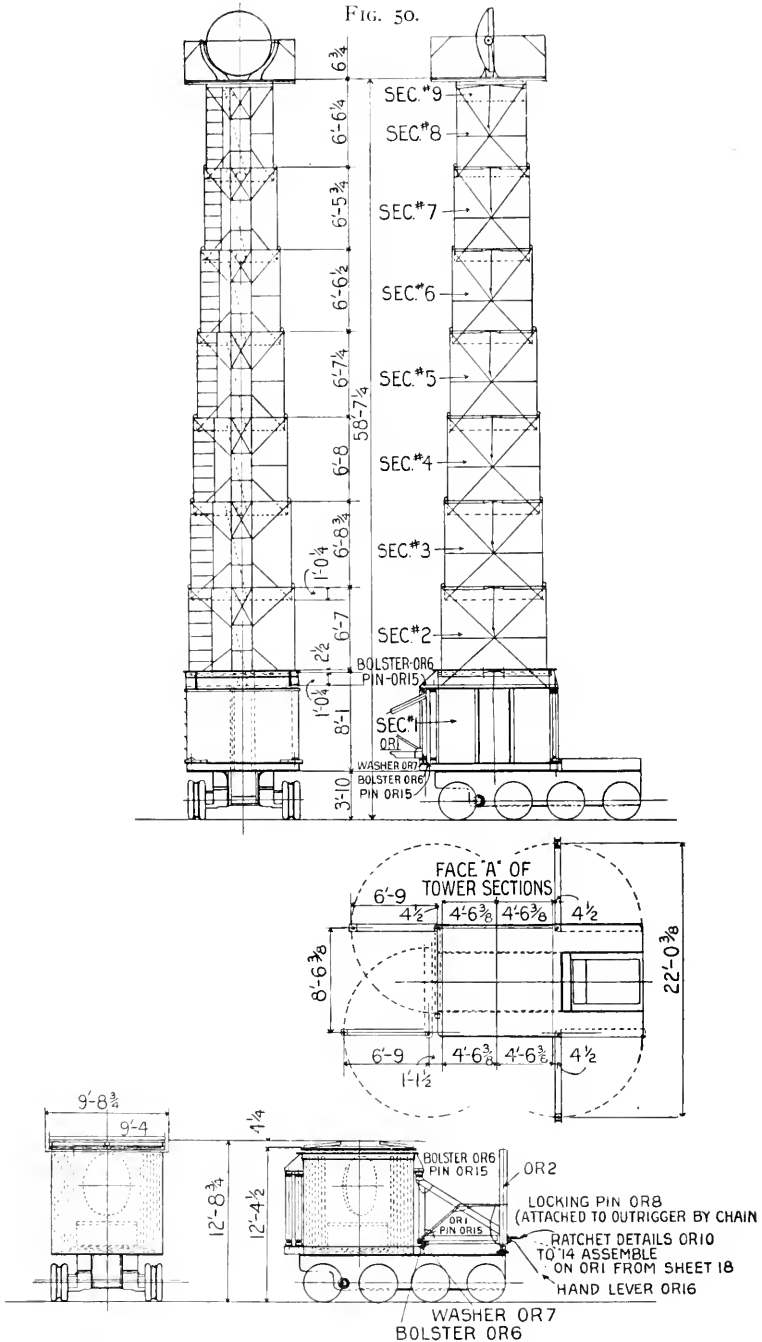
1919 design of mobile searchlight tower and mount. Searchlight is 60-inch open type design and can be raised 60 feet above the surrounding terrain by the extensible tower. The entire equipment is carried on an eight wheeled, self-propelled carriage, which in addition carries a 500 ampere generator.

by the temperature at which that source operates and by the amount of energy available for conversion into light. The color of the source or its spectral energy distribution is almost wholly dependent on the maximum temperature of the source. The total amount of energy available as light is usually measured by any one of several well-known photometric schemes. Two of them have been very widely used in the recent investigations of searchlights.

ARC ILLUMINATION.

65. One method of measuring arc illumination uses a standard photometer and several mirrors. The photometer and the source of light are held fixed in position. The mirrors are so arranged that they will reflect the light given from any one sector of the source into the photometer. The mirrors are rotated about the source step by step in three great circles. Photometric observations are made at each step. The observations are repeated in order to insure average conditions and the result is plotted as a characteristic curve. A reproduction of such characteristics for various kinds of searchlight arcs are given in Figs. 51, 52 and 53. These represent not only the distribution of flux of illumination from the source of light, but also the total quantity of light that can be expected in any given portion of the perimeter.

66. Another method used for determining the illumination of a source is an application of the hemispherical photometer. The concave side of a hollow hemisphere, painted a matte white, is used for receiving, collecting and reflecting the light into the receiving glass of a photometer fixed behind the hemisphere and on its axis. The observations give the total light from an arc or from the beam when a mirror is placed behind the arc. This method gives a relatively rapid means for obtaining the total flux of illumination in a searchlight beam, and has been used with marked advantage for this purpose. The results are given as a total figure and not as a characteristic curve.

SPECTRUM ENERGY.

67. Spectrum energy distribution characteristics of sources of light for searchlights are of prime importance. Their form gives the distribution of the light energy in the source. The maximum point of this characteristic gives a clew to the tem-

perature of the source. A study of their shape reveals the efficiency and the usefulness of the source. There are several methods used for obtaining spectral energy distribution. One is

FIG. 51.
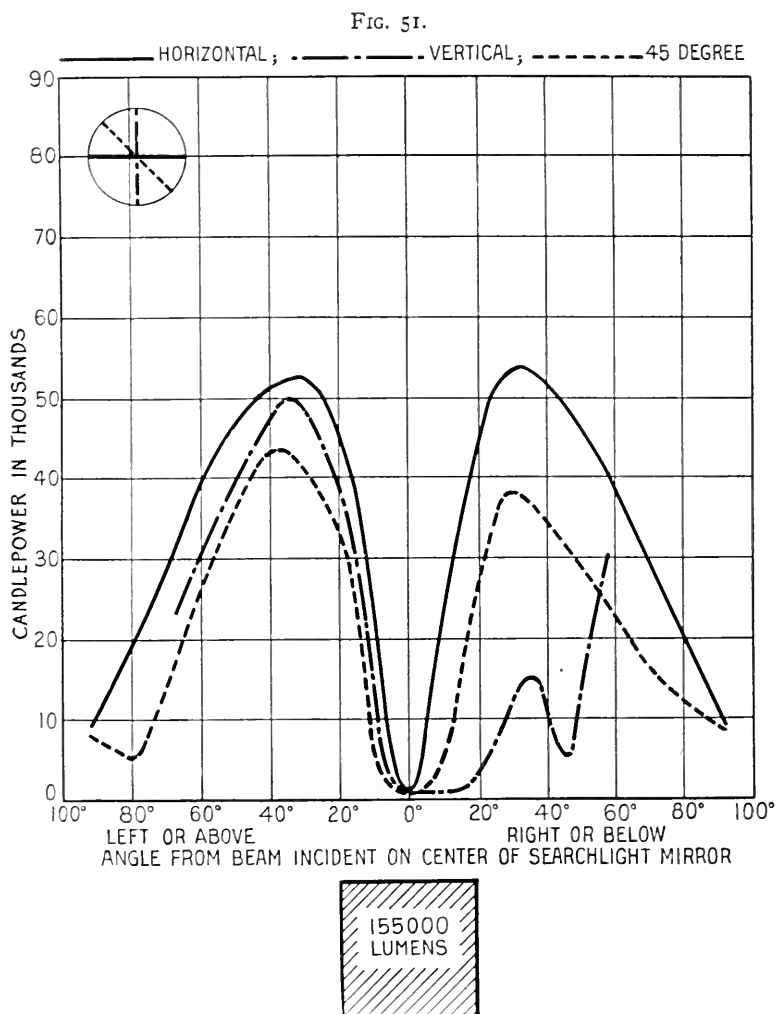
Graph illustrating distribution of illumination of a 195 ampere, 65 volt low intensity search-light arc.

by the spectro-photometric scheme. The other is by the bolo-metric scheme. In the spectro-photometric method, a polariza-tion spectro-photometer with a polarization photometer and

illumination box is used with certain auxiliary apparatus.   In this apparatus, the source of light, whose spectral distribution is to be examined, is compared with a standard source of light.

FIG. 52.
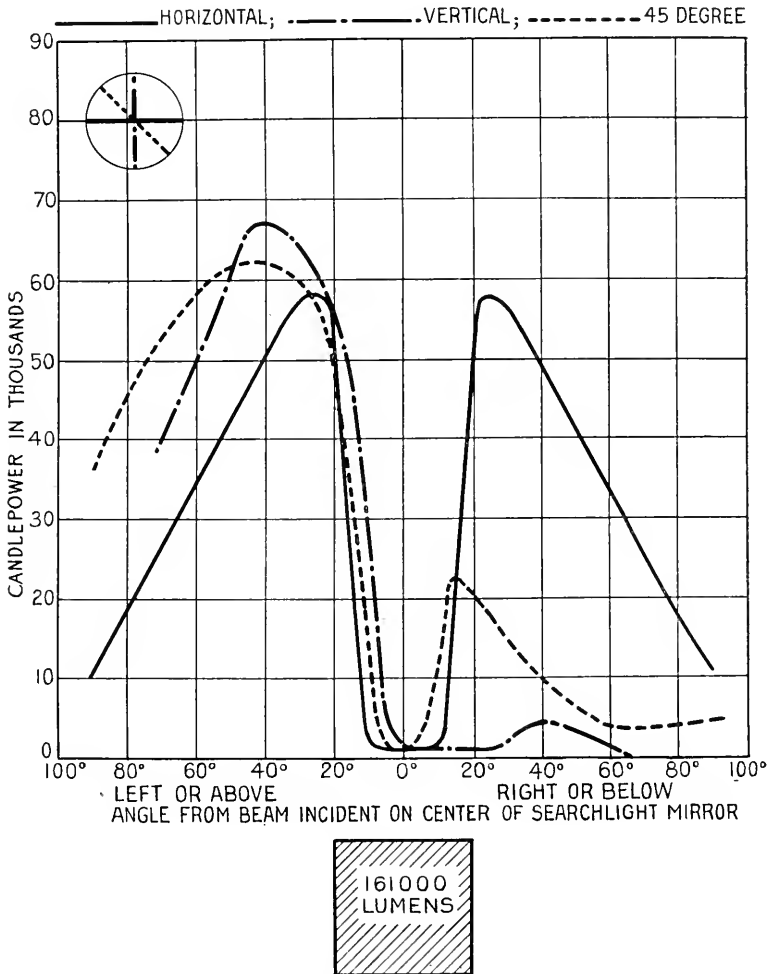
Graph illustrating distribution of illumination of a 200 ampere, 65 volt medium intensity search-light arc.

For all of the comparisons made during the last two years on searchlights, a 500-watt, type C Mazda lamp was used as a standard.   It was operated at a constant voltage of such value

that its characteristics were known. The relative value of the
radiant power of the arc under observation as compared to the

FIG. 53.
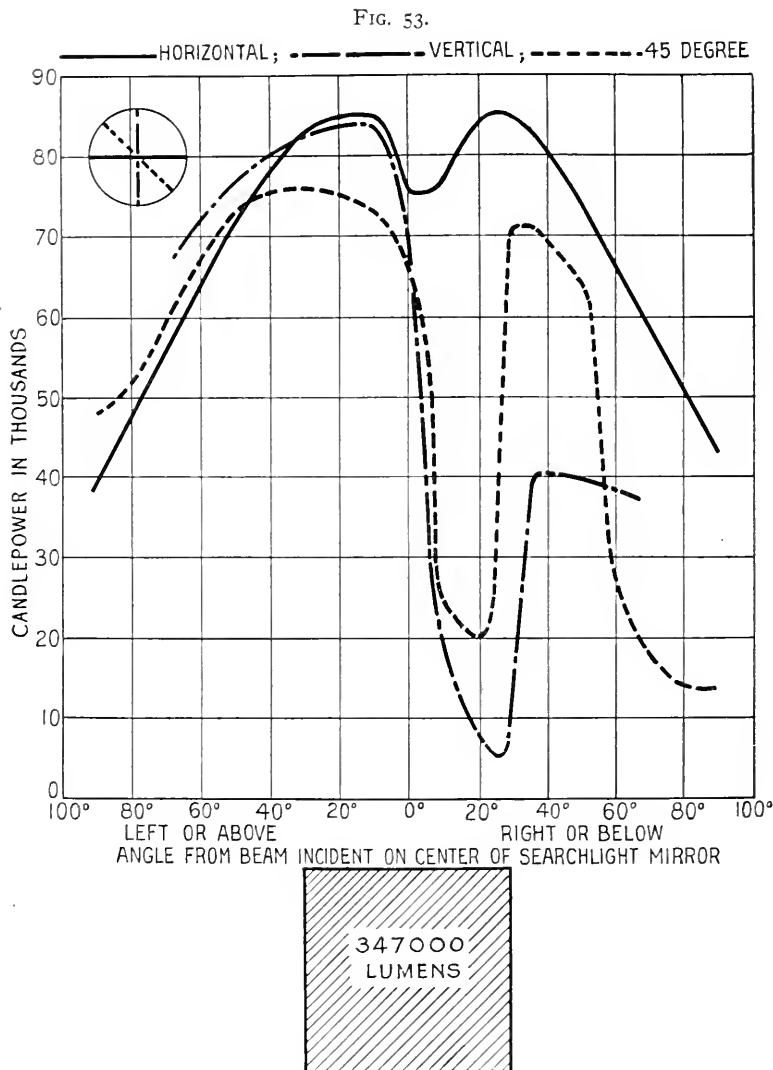
Graph illustrating distribution of illumination of a 150 ampere, 75 volt high intensity search-
light arc.

standard was obtained visually spectro-photometrically. The
light from the test source and the comparison source were con-

densed and made to enter the illumination box from opposite
sides. In the box they fell on magnesium carbonate blocks. Pre-
cautions were taken to eliminate the color difference between the
intensely white light of the searchlamp source and the relatively
yellow light from the type C Mazda lamp. The measurements
were laborious and tiresome, but gave relatively accurate results.
A reproduction of one set of measurements is given in Fig. 54.

68. The bolometric method of determining the spectral dis-
tribution of energy of a light source is very much simpler. It
consists essentially in directing a beam from the source through

Fig. 54.
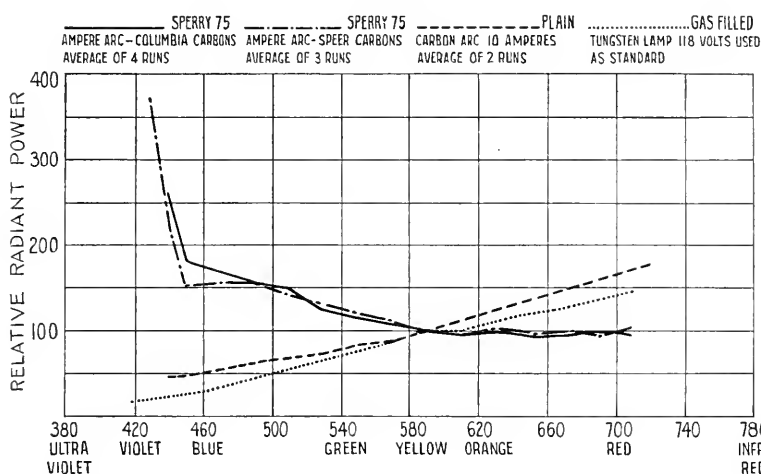
Spectral energy distribution of high intensity arcs used for searchlights, as compared with plain carbon arc and gas filled tungsten lamp.   Wave lengths are in 10^9 meters.

a prism onto a sensitive thermopile, connected to a sensitive
galvanometer. The prism is rotated slowly, and thus various
bands of the spectrum are directed onto the thermopile suc-
cessively. The thermopile responds to the amount of radiant
energy it receives from each band and gives a corresponding
deflection to the galvanometer. A beam of light reflected from
a mirror on the galvanometer suspension traces a graph on a
rotating sensitive film, suitably placed. The result is an accurate
graph showing the distribution of radiant energy in the spectrum,
taken without the direct aid of any human organ. This equip-
ment has been principally used for observing the spectral dis-

tribution of energy in searchlight beams rather than sources of light. Characteristics so taken are given in Fig. 55.

ATMOSPHERIC ABSORPTION.

69. The effect of the absorption of radiant energy by the atmosphere has been studied from time to time. It is found that the energy-absorbing characteristics of the atmosphere vary through very wide limits and are affected by many factors for which there are at present no well-established standards of measurement. For example, the present meteorological determina-

FIG. 55.
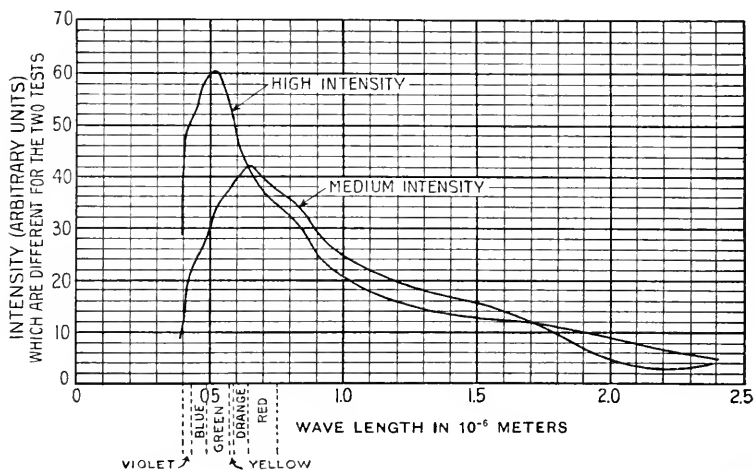
Spectrum energy distribution in beams of high intensity and medium intensity arc searchlights.

tions give the amount of moisture in the atmosphere, but do not state how this moisture is distributed. It may be in the form of a mist composed of very fine drops or it may be in the form of a rain composed of relatively large drops. The mist is an almost impenetrable screen for a searchlight beam, while the rain curtain can easily be penetrated. Then again, the amount of dust in the atmosphere is an important feature, tending to reduce the amount of light transmitted from a searchlight source. Hence, it is seen that a study of the atmosphere is relatively important in connection with a study of searchlight characteristics. On the other hand, it must be realized that the searchlight must be used under all atmospheric conditions. For this

reason, while a knowledge of the various atmospheric conditions will be of advantage in the operation of searchlights, yet it is not fundamentally necessary. For a thorough consideration, however, of searchlight characteristics, a general idea of the effect of atmospheric absorption is quite important.

70. Tests have been made of atmospheric absorption during a long period of time by the physicists of the Smithsonian Institution. The results of their investigations are shown in Fig. 56. It is seen that layers of air, such as are used in ordinary search-

Fig. 56.

WAVE LENGTH IN 10^{-6} METERS
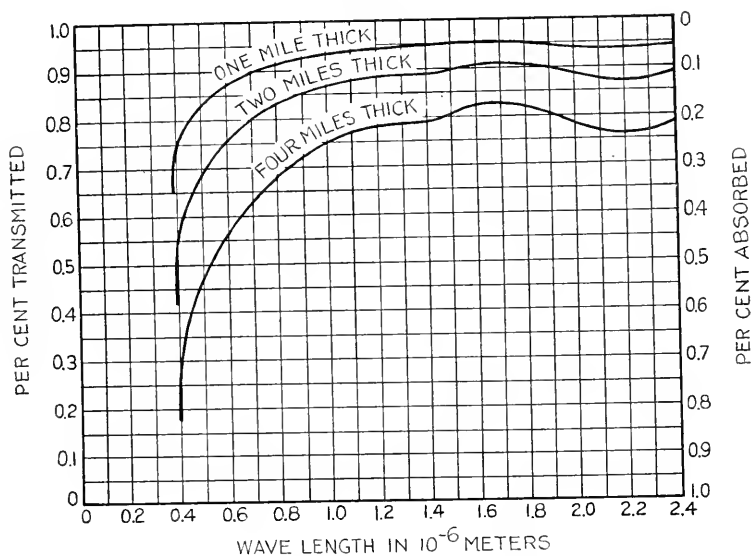
Radiant energy absorption characteristics of clean, dry air.

light illumination, absorb a very large quantity of the light flux produced at the source, and thereby the atmosphere introduces an important absorbing factor in searchlight operation. These characteristics also indicate the more rapid dissipation of the shorter wave-lengths of radiant energy than of the longer wave-lengths. One result of this is to make a white source appear yellow at a distance of 15 to 20 miles. Another effect is to partially nullify the illuminating value of the high-efficiency (intensity) arcs. These have a maximum in the green, while the medium-intensity arcs have a maximum in the yellow. The high-intensity arcs have a larger proportion of blue light than

do the medium-intensity arcs. However, since the radiant energy in the blue portion of the spectrum is very much more rapidly dissipated in the atmosphere than is the radiant energy in the yellow and red portion, it is found that a greater amount of the radiant energy produced by the high-efficiency arcs is absorbed in the atmosphere than is the radiant energy from the medium-intensity arcs.

BEAM ILLUMINATION.

71. The photometering of searchlight beams has proven relatively difficult. Several methods have been tried. The only one which has proven successful up to the present time uses standard photometers. In one application of this method, the searchlight beam is held stationary and either the photometers or reflecting screens are moved across horizontal and vertical diameters. In another application the photometer is held fixed in position, and the beam is moved across it and observations taken point by point. Both methods depend on the accuracy and the training of the observers and besides are affected by the absorbing characteristics of the atmosphere. However, the results give the shape of the illumination distribution curve in the beam, even though the intensities and the total flux values may vary through wide limits with atmospheric changes. The results of a series of tests made at 2300 feet ranges with various kinds of searchlights are given in Figs. 57, 58, 59 and 60. They represent the characteristics of low-intensity, medium-intensity and high-intensity arc searchlight beams when projected from barrel-type and open-type searchlights. They are shown comparatively to give an idea of the relative values of various searchlights.

72. A proposed scheme of examining the distribution of illumination in a searchlight beam is an application of the bolometer with a suitable correcting screen. The screen consists essentially of a cell containing a liquid which passes radiant energy in practically the same proportion as the eye is influenced by it. The light, after passing through the cell, is projected onto a sensitive thermopile which is connected to a reflecting galvanometer. A number of these instruments may be placed across the horizontal and vertical diameters of a searchlight beam and practically simultaneous observations obtained of the deflections of the galvanometers. This method may be used for measuring the absolute distribution of energy or the relative distribution

of energy in the beams. The character depends upon the source used as a standard. This scheme has been tried and found

Fig. 57.
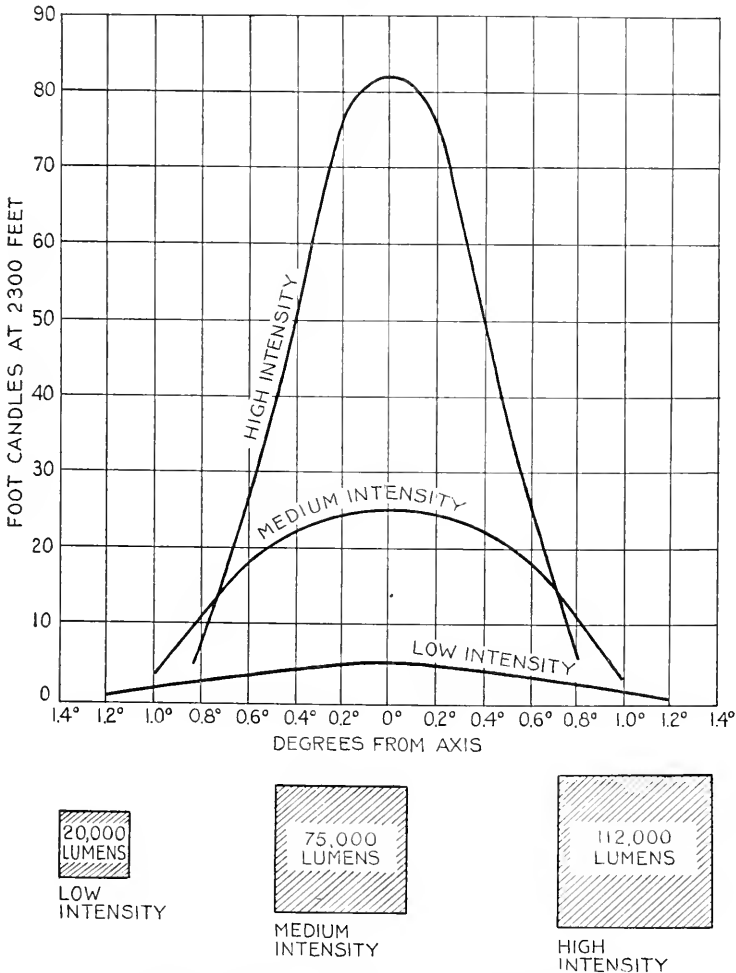
Comparative flux distribution of illumination in beams of low intensity, medium intensity and high intensity arc barrel type searchlights.

effective. It has not, however, been developed to a point of wide application.

TARGET COMPARISONS.

73. The most useful method of examining a searchlight beam is in connection with the type of target with which it will be used.

Recently a number of tests have been made at one of the large
aviation stations where moving airplanes were used as targets.
Various kinds of searchlights were tested in combination with the

Fig. 58.
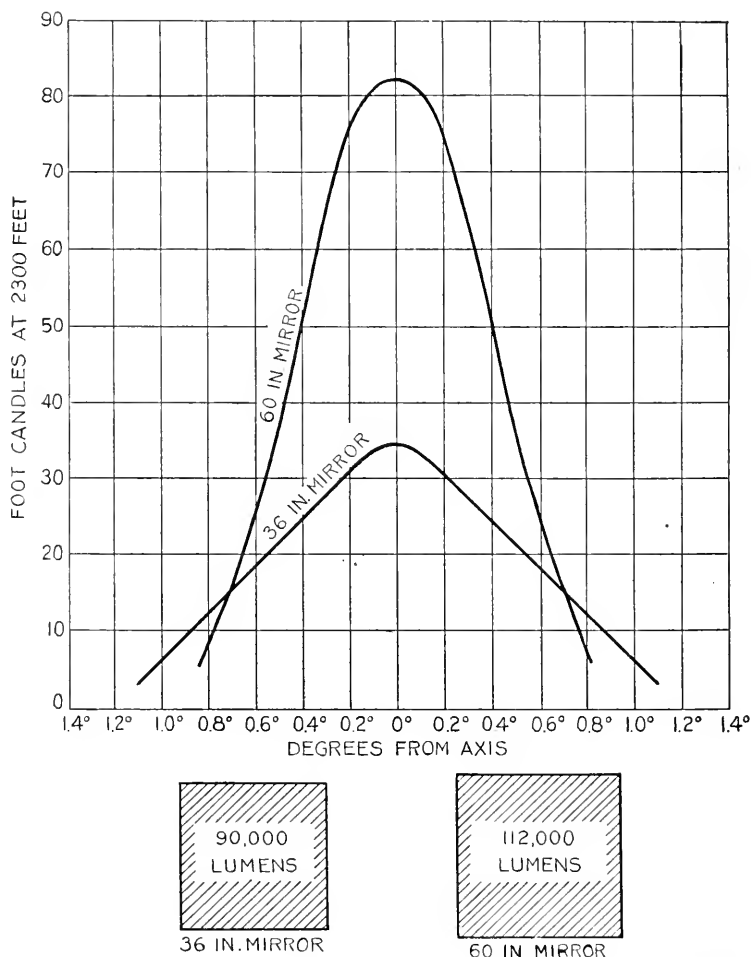
Comparison of flux and illumination distribution in beams of 36-inch and 60-inch barrel type of
searchlights, both having the same light sources.

airplanes. The searchlights have been described on preceding
pages. The type of airplane used is shown in Fig. 61. The
results of the tests which give characteristic pick-up values for
the searchlights are shown in Figs. 62, 63 and 64. These illustrate

what might be termed " the range characteristics of searchlights
used in picking up airplanes." It should be noted that all of the
curves shown exhibit the same characteristic. They are practi-

Fig. 59.
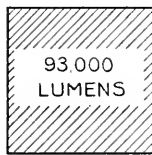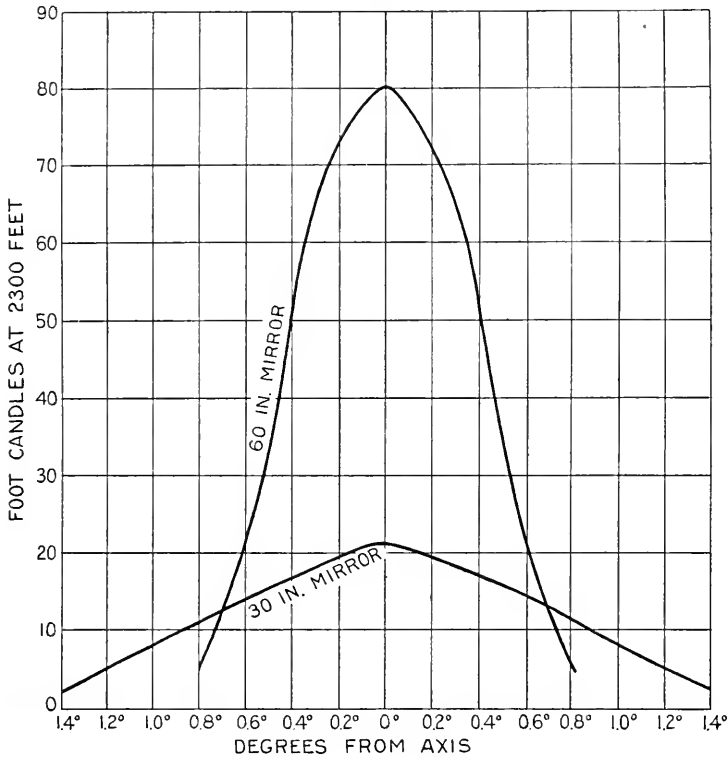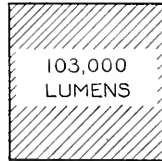
Comparison of flux and illumination distribution in beams from 30-inch and 60-inch open type
searchlights, both having the same light sources.

cally flat up to a limiting point beyond which they rapidly drop
away until a second limiting point is reached, at which they more
gradually approach an asymptotic relation. The first point at
which a change in the curvature occurs is probably caused by the

difference in the observing powers of the eyes of the observers. The second point of curvature in the characteristic is probably caused by the approach of the threshold of vision of the various

FIG. 60.
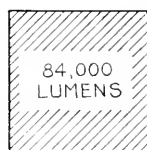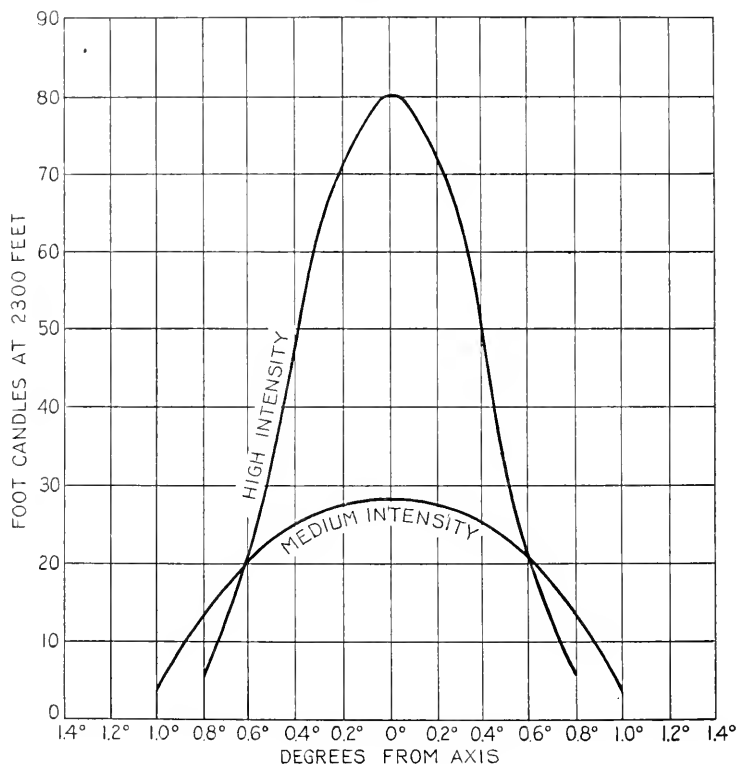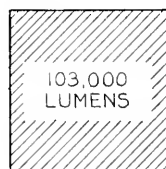
Comparison of flux and illumination in beams from 60-inch open type searchlights with high intensity and medium intensity arc light sources.

observers. In this connection it is interesting to note that the same observers have been able to pick up airplanes at about twice the range in daylight as they pick them up at night with the searchlight, whose characteristic is shown in Fig. 63.

Fig. 61
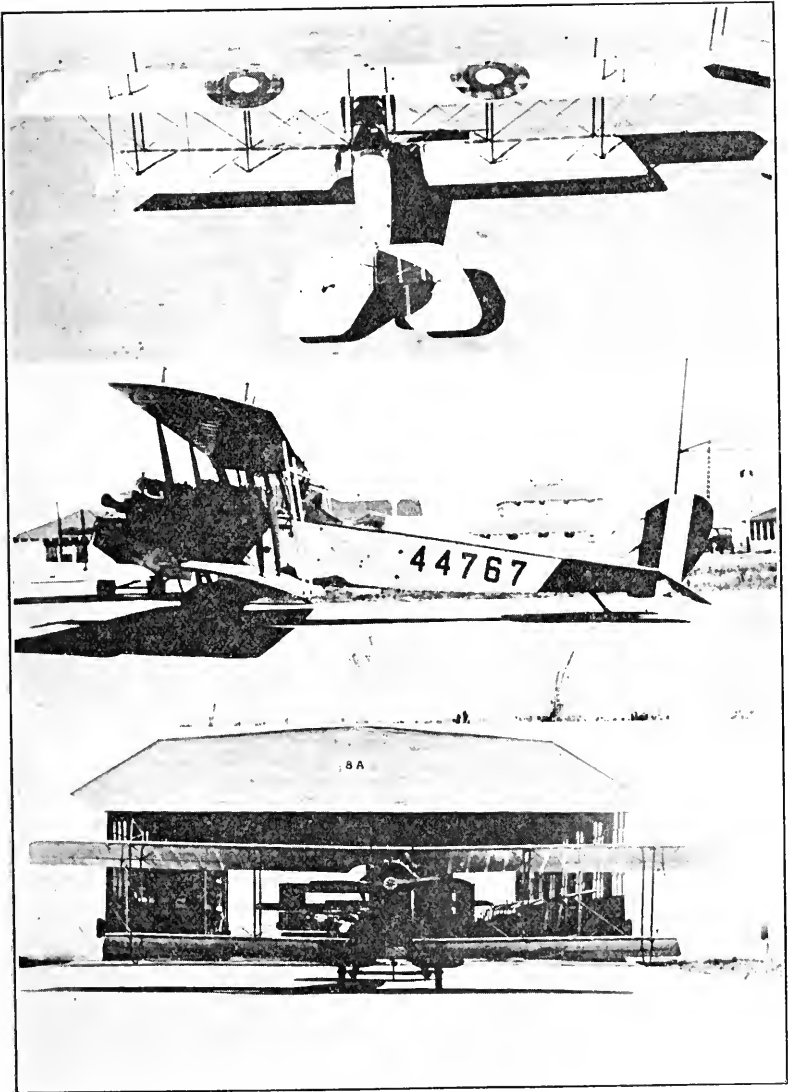
Typical airplanes such as used for making target comparison tests.

BEAM COLOR.

74. A great deal is said from time to time concerning the best color of the beam of a searchlight. This characteristic has

Fig. 62.
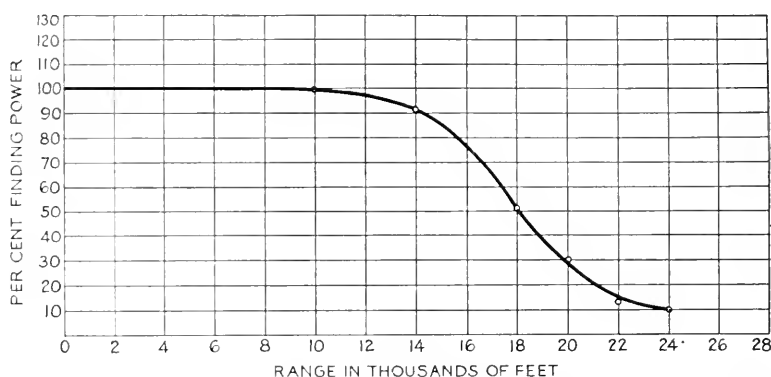
Airplane finding power characteristic of 30-inch, 150 ampere high intensity, open type searchlight

been found to be dependent principally upon the temperature of the source and the kind of mirror. At relatively low temperatures, that is, with low intensity arcs having a current density

Fig. 63.
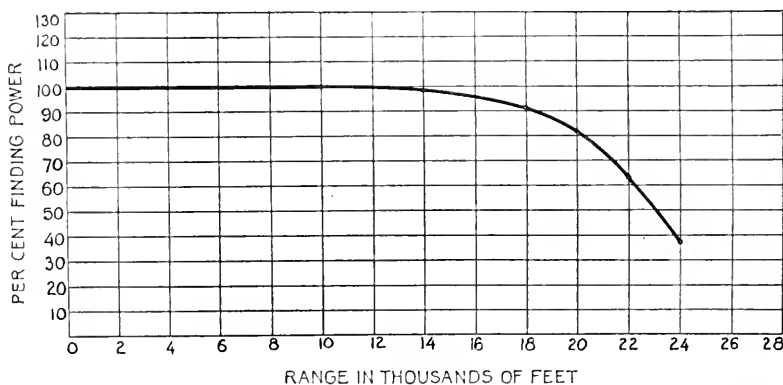
Airplane finding power characteristic of 60-inch, 150 ampere high intensity, open type searchlight

of about 0.3 amp./sq. mm., the color is reddish yellow. Ingredients in the cores of the carbons can be used to modify the color of the beam. At intermediate temperatures, such as produced by medium-intensity arcs having current density about 0.6 amp./sq.

mm., the color of the beam is greenish yellow. Ingredients in the cores of electrodes have slight modifying effect on the color. At high temperatures, such as produced by high-intensity arcs with a current density of about 1.0 amp./sq. mm. the beam color is bluish white and is uninfluenced by ingredients in the cores of the electrodes.

75. The color of a searchlight beam can be accurately controlled by the use of a ray filter. Such filters, however, reduce the amount of light in the beam from 20 to 50 or more per cent. Their use has been abandoned for military purposes where the amount of light is of paramount importance. Besides, it has

Fig. 64.

RANGE IN THOUSANDS OF FEET
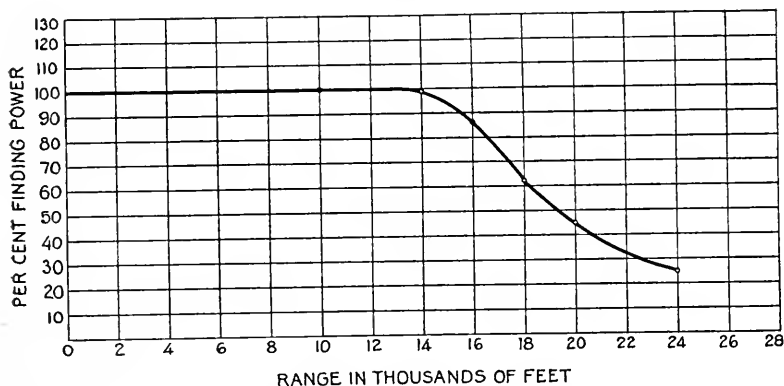
Airplane finding power characteristic of 60-inch, 200 ampere medium intensity, open type searchlight

been found that the color of the light is not nearly so important as the quantity of it and its distribution.

TACTICS.

76. The tactical operation of searchlights varies with the kind of military situation to be met. Before the advent of the airplane, searchlights were used for illuminating bodies of troops, battleships and other objects on the earth's surface. Such objects were relatively slow moving and at the same time relatively large in size. They moved in one plane and as much as thirty minutes or even two hours could be allowed for finding them. The method used was to sweep the landscape slowly until the target was picked up, then the light would be held fixed on it for such

offensive operations as had been determined. The advent of the airplane in warfare, however, changed the tactical operation of searchlights. They were required to search in three dimensional space instead of in a plane. This increased the difficulty many fold. Beside, the targets were relatively small in size, fast in speed and agile in movement. In addition, the development of accurate range-finding devices reduced the time that a searchlight beam could be safely exposed. As a result, the *time* of searching has been reduced to a maximum of about thirty *seconds* and the *method* of searching radically changed.

77. Searchlights are also used in military operations for signalling between distant points, particularly in day time and as beacons for airships. The signalling is done by means of some form of shutter which operates the searchlight in much the same manner as the ancient heliograph. For beacon work the searchlight is operated as is a lighthouse, excepting that the beam is usually elevated from five to ten degrees above the horizontal and the searchlight is usually located on the ground instead of being elevated in the air.

RANGE.

78. Frequent reference in the literature is made to the range of a searchlight. This is not a definite value. It depends on the size of the target, the amount of surface which the target exposes, the speed of the target and principally the amount of light from the source and the absorbing qualities of the intervening atmosphere. The usual range at which an airplane can be picked up is about 15,000 feet, while the same searchlight can usually pick up a battleship at 40,000 to 50,000 feet. These values apply only to relatively clear weather. On foggy nights it is impossible to pick up either the airship or the battleship at 2000 feet, while on rainy nights the range for the two types of targets may be 10,000 and 30,000 feet respectively. The high-intensity arc searchlights can pick up a target at a greater range than can the medium-intensity searchlights. This is, however, due to the fact that for the same energy input the high-intensity arcs give a greater total light flux at the source than do the medium intensity arcs. It has been found, however, that where both kinds of arcs have the same amount of flux at the source that the medium-intensity arc had a greater range than the high-intensity arc.

Of course, this increased range is obtained with the expenditure of more energy in one case than in the other.

FUTURE.

79. The future development and use of searchlights seems assured. The increasing use of night operations in military manœuvres requires a wider application of means for detecting and illuminating the enemy. This means that more than ever before use will be made of searchlights in limiting enemy operations.

80. The development of searchlights will probably proceed along lines which will reduce the weight of the equipment and increase its effectiveness. The searchlight itself has, within the past two years, been reduced more than 80 per cent. in weight. The generating plant has only been reduced about 20 per cent., while the cable weight has only been reduced about 15 per cent. It seems, therefore, logical to expect that future developments will seek to reduce the weight of the generating and distributing equipment so that there may be produced a searchlight equipment of the highest possible efficiency and utility.

Washington, D. C.,
   February 11, 1920.

Question cf Priority.—The name of John Dalton has been for over a century connected with the establishment of the atomic theory as generally applied in chemistry, but his claims to the foundation of it have been disputed in a paper recently published by Andrew Norman Meldrum, I.E.S., Fellow of Bombay University. Meldrum's paper is fundamentally a criticism of the presidential address of Alexander Scott, delivered March 29, 1917, at the annual general meeting of the Chemical Society. Scott's subject was " The Atomic Theory," with especial reference to the work of Stas and Prout's hypothesis. According to Meldrum, many of the statements in the address are open to criticism, both as to data and inferences, but the most interesting point is the claim that William Higgins, who was an early convert to the antiphlogiston views of Lavoisier, anticipated Dalton by about fourteen years in the suggestion of the atomic theory. Meldrum traces the development of the theory back to Newton, who advanced the view that an elastic fluid is composed of particles mutually repellent. Quite a number of other scientists of the seventeenth century were more or less connected with the development of the theory, one important reason for such interest being that they

were, as was the custom at that time, good classical scholars and, therefore, familiar at first hand with the early Greek philosophers, who, as is pointed out in our histories of chemistry, suggested a theory of the composition of matter which is singularly like that dominant to-day. Meldrum's essay " The Development of the Atomic Theory " is interesting throughout.

H. L.

On the Electrical Conductivity of Copper Fused with Mica. SUB-LIEUT. A. L. WILLIAMS. (*Phil. Mag.*, September, 1920.)—To prepare the material an electric arc was struck between an iron or copper plate serving as an anode and a carbon rod as cathode. The arc was shifted over to the mixture of copper and mica lying on the plate and fusion followed. " In making up the samples studied, about equal proportions of copper and mica were used." The resulting material seems to be uniform throughout, about as hard as glass and more brittle than copper. It is malleable at 2000° C. The outstanding characteristic is the great reduction in its electrical resistance caused by an increase of temperature. A specimen whose resistance was 91,010 ohms at 99° C. was found to have only 11,370 ohms at 228° C. For another specimen the data are 16,000 ohms at 27° C. and .5 ohm at 850° C. For mixtures of iron and mica similar results were obtained.

The author makes the suggestion that the copper-mica mixtures may prove of use in signalling and in sound-ranging " as the changes of resistance, due to changes of temperature, are quite considerable, being some thousands of ohms per degree centigrade with some samples."

Prof. J. C. McLennan of the University of Toronto has caused the experiments to be repeated and extended in his laboratory by Miss Mackey and Miss Giles. Some of the results above quoted are from their data.

G. F. S.

High Altitudes in the United States. (*U. S. Geological Survey Press Bulletin* No. 457, October, 1920.)—Many people believe that Mount Washington, in New Hampshire, is the highest mountain in the eastern part of the United States. Mount Washington stands 6293 feet above sea level, according to the Survey, but many peaks in the Southern Appalachians are several hundred feet higher than New Hampshire's famous mountain. The highest mountain in the Appalachian system—the highest point in the United States east of the Rockies—is Mount Mitchell, in North Carolina, which stands at an elevation of 6711 feet. The highest mountain in Tennessee, Mount Guyot, stands 6636 feet above sea level.

RECOMMENDED SPECIFICATIONS FOR VOLATILE MINERAL SPIRITS FOR THINNING PAINTS.[1]

[ABSTRACT.]

THIS specification, prepared under the auspices of the Bureau of Standards, is one of the series of specifications for paint materials approved by an interdepartmental committee of Government experts. In addition to the general statement of requirements, there are given detailed instructions as to sampling, laboratory examination, and basis of purchase. The standards were finally submitted to representatives of the petroleum and the paint and varnish industries and the suggestions considered in the final revision.

AIR FORCES ON CIRCULAR CYLINDERS, AXES NORMAL TO THE WIND, WITH SPECIAL REFERENCE TO DYNAMICAL SIMILARITY.[2]

By Hugh L. Dryden.

[ABSTRACT.]

ONE of the most difficult problems of the airplane designer is to obtain a method of computing forces on full-size machines or full-size machine parts from measurements made on models in a wind tunnel. A certain equation deduced from theoretical considerations has long been known and used, namely, the equation proposed a long time ago, first by Helmholtz, later stated by Reynolds and developed more fully by Lord Rayleigh and Buckingham. This equation is a logical consequence of certain assumptions and states that, if these assumptions are true, the force of a current of air upon a solid body may be expressed as $C\rho AV^2$, ρ being the density of the air, A the area of the body projected on a plane normal to the wind, V the velocity of the

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* Communicated by the Director.
[1] Circular No. 98.
[2] Scientific Paper No. 394.

wind, and C a dimensionless constant depending on a single parameter $\frac{VL}{v}$, where v is the kinematic viscosity of the air and L is a linear dimension of the body. This equation then implies that if C be plotted against $\frac{VL}{v}$, the points will fall on the same curve independent of the individual value of V or L, provided the bodies are geometrically similar and presented in the same manner to the wind.

This law is a logical consequence of the assumptions. Although some tests have been made of the validity of the assumptions in the case of wind-tunnel experiments, no extensive investigation of a body of simple geometrical form over a large range of values of V and L has been published. The present paper gives the results of tests on cylinders for different values of L. An attempt was made to make the assumptions involved in the derivation of the equation true as closely as is possible in wind-tunnel experiments.

Cylinders of 1, 1¼, 1½, 1¾, 2, 2½, 3, 4, 4½, 5, 5½, and 6 in. (.0254 to .1524 m.) were used at velocities from 15 to (in the case of the smaller cylinders) 80 miles per hour (25 to 130 km. per hour approximately). The range of values of $\frac{VL}{v}$ was from 10,000 to 185,000. The cylinders were made of wood with the exception of those less than 2 in. in diameter, which were of brass; but an additional 1-in. wood cylinder and 4-in. brass cylinder were also used. The "guard ring" principle was used to obtain results applicable to infinite cylinders.

The results show that the equation does not represent the facts of wind-tunnel experiments in the case of cylinders. The coefficient C for a 1-in. cylinder is half again as large as that for a 3-in. cylinder at the same value of $\frac{VL}{v}$. Above a 3-in. diameter the equation is satisfied closely, the coefficient being practically constant and equal to 0.426. The curve for the 1-in. cylinder checks N.P.L. values closely. The maximum departure of any one observation from the mean is about 2½ per cent. Measurements of the pressure distribution showed that in the case of the small cylinders the ratio of the average decrease in pressure on the back to the maximum increase in pressure on the front is greater than in the case of the larger cylinders.

CAST IRON FOR LOCOMOTIVE CYLINDER PARTS.[a]

By C. H. Strand.

[ABSTRACT.]

Frequent renewal of cylinder parts of locomotives results in greatly increased cost of maintenance to the railroads, and consequently the quality of the cast-iron entering into their construction is a matter of paramount importance, particularly from the standpoint of wear. These parts include piston-valve bushings, piston-valve packing rings, piston-valve bull rings, cylinder bushings, piston packing rings and piston-head or bull rings. It was found that ordinary high-silicon cast-iron gave unsatisfactory wear, particularly in modern superheater locomotives, and the tendency has been towards a harder and stronger iron.

At the request of the U. S. Railroad Administration, the Bureau of Standards has investigated the mechanical, chemical, and microscopical properties of a number of packing rings furnished with service mileage records, as well as arbitration-test bars, chill-test specimens, and miscellaneous samples from different manufacturers. All of this material was cast-iron such as used for the various cylinder parts. The Bureau of Standards at the same time made a review of the previous work and specifications on this subject, to ascertain as far as possible the practices of the different foundries, and to suggest such revision of existing specifications as would be warranted by the results of the present and other investigations.

It was found that air-furnace iron is more uniform in character and in general of somewhat better mechanical properties than cupola iron. The latter, however, often equals or even excels the air-furnace product in mechanical properties. Because of the many variable factors, it was difficult to establish correlation between laboratory and service tests. It was recommended, as a result of the present and other investigations, that the transverse-strength requirements of the Standard American Society for Testing Materials $1\frac{1}{4}$-inch Arbitration Bar be increased from 3200 to 3500 lb. for castings $\frac{1}{2}$ in. or less in thickness, and from 3500 to 3800 lb. for castings over $\frac{1}{2}$ in. in thickness.

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[a] Technologic Paper No. 172.

It is shown that for a very slow rate of heating this transformation is practically independent of carbon content, and that it then ends at about 260° C. This temperature undoubtedly represents the end of the transition of martensite into the troostite of tempering. The transformation is also closely associated with the physical changes accompanying the tempering of hardened steel.

A STUDY OF THE RELATION BETWEEN THE BRINELL HARDNESS AND THE GRAIN SIZE OF ANNEALED CARBON STEELS.[6]

By Henry S. Rawdon and Emilio Jimeno Gil.

[ABSTRACT.]

In some of the simple alloys a rather definite relation exists between grain size and hardness. A study was made of five types of carbon steel in various conditions of grain size to determine whether such a relation exists for steels. The variations in grain size were produced by annealing for long periods at different temperatures and also by low-temperature annealing after a preliminary straining of the metal. Two methods were used for obtaining the hardness values, the standard Brinell apparatus and a small type, designated as the " micro-Brinell " testing set, by which the hardness of individual grains could be measured.

In general there appears to be no definite relation between grain size and Brinell hardness, except in the case of a very pronounced increase in grain size, which is usually accompanied by a decrease in the hardness.

The general effect of heating steel, i.e., in annealing, is to harden it appreciably, this increase in hardness is noticeable in spite of any sharp drop which may accompany an abrupt change of grain size.

The rate at which steels are cooled, and consequently the structural condition of the hardening constituent, affects the hardness much more than any other factor.

Incidental to the study of the hardness of steels coarsened by annealing after permanent strain, some data were obtained relative to the magnitude of the necessary stress required to cause pronounced grain growth upon annealing such strained metal below the A_1 transformation temperature.

[6] Scientific Paper No. 397.

Platinum in 1919. (*U. S. Geological Survey Press Bulletin* No. 457, October, 1920.)—The United States is still dependent on foreign countries for its supply of platinum. The small output of crude platinum from domestic mines increased from 647 ounces in 1918 to 824 ounces in 1919, but the total quantity of refined platinum and allied metals recovered from foreign and domestic ores by domestic refiners decreased from 59,753 ounces in 1918 to 45,109 ounces in 1919. Only 11,759 ounces of refined platinum were derived from domestic ores in 1919. On the other hand, the imports of platinum and allied metals increased from 56,753 ounces in 1918 to 68,054 ounces in 1919, nearly half of which came from Colombia. The estimated world's production increased from 62,283 ounces in 1918, the lowest recorded output, to 67,180 ounces in 1919, but was still far below that of preceding years.

During the war 83 per cent. of the platinum metals consumed in this country were used in essential industries (chemical, electrical, and dental), but in 1919 only 40 per cent. were so used, and the quantity used for jewelry increased from 12 to 56 per cent. The remaining small percentage was divided among several minor uses.

A report on "Platinum and Allied Metals in 1919," by J. M. Hill, recently issued by the Survey, shows the production, consumption, market, and prices, and contains notes on deposits and mining in the United States and the leading foreign countries.

A New Primary Electric Cell. (*La Nature*, September 18, 1920.) —During the war the French army needed a great number of cells of the Leclanché type. France had no manganese dioxide and it was difficult to obtain it from the outside world. Féry succeeded in devising a cell which does not polarize in spite of its lack of the dioxide. At the bottom of the solution is a flat horizontal plate of zinc, to which is soldered a wire forming one terminal of the cell. A cylindrical, porous carbon rests on a thin piece of insulating material which is supported by the zinc. The carbon carries a terminal post. As soon as the current flows hydrogen forms on the part of the carbon close to the zinc. The superficial layers of the liquid have absorbed oxygen from the air. The upper part of the carbon is therefore in a liquid rich in oxygen while the lower part is coated with hydrogen. A gas cell results, the upper part of the carbon being positive and the lower part negative. In consequence of this oxygen is liberated at the lower part and combines with the hydrogen, causing polarization. Hydrogen is set free at the upper end of the carbon and combines with the dissolved oxygen. The operation of the cell therefore depends on the action of oxygen dissolved from the air.

The salt of ammonia is regenerated within the cell, there are no creeping salts and the zinc is not attacked on open circuit. A reduction in cost results from the elimination of the manganese dioxide.

G. F. S.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

BACTERIAL DECOMPOSITION OF SALMON.[1]

By Albert C. Hunter.

[ABSTRACT.]

AN extended bacteriological study was made of salmon held at temperatures between 50° F. and 70° F. until they had reached an advanced stage of decomposition. At twenty-four-hour periods total counts of bacteria were made on the muscular tissue of the back and belly, and agar slant cultures were made from the mouth, gills, stomach, cæca, intestines, heart, liver, and kidney. Experiments were conducted to determine the effect of thoroughly washing the fish as soon as they were brought ashore. The results may be summarized as follows:

1. The muscular tissue of freshly caught salmon is sterile.

2. After ninety-six hours at temperatures between 50° F. and 70° F., the total count of bacteria in the muscular tissue has been found to be as high as 155,000,000 per gram. The high counts obtained are sufficient to explain the decomposition of the tissue.

3. Thoroughly washing the fish on arrival at the dock results in lower total counts. The washed fish decompose less rapidly than the unwashed fish.

4. The mouths and gills of salmon contain living micro-organisms of various kinds, even when fresh from the water.

5. The digestive tract of salmon is sterile when there is no food present.

6. The various organs of the body become infected through the blood-vessels, usually within ninety-six hours after the fish are caught.

7. Salmon out of water more than forty-eight hours at temperatures between 50° F. and 70° F. are decomposed to such an extent that they are not desirable as food.

POPULAR NAMES OF CRUDE DRUGS.[2]

By Arno Viehoever.

[ABSTRACT.]

The purpose of this article is simply to advocate greater care in the use of common names. Where the product is already well known, even by a name which is obviously unsatisfactory, the desirability for another, though proper name, might not be so apparent. In cases, however, where new products are introduced, it is essential that some thought be given to the proper common, as well as scientific, name. A name may already be attached to the product, given to it by some one qualified or not qualified. Discrimination must therefore be used in the choice, and great care in the creation of a name, if no suitable name is available.

After discussing the varied bases of common names for crude drugs, the following rules are suggested for selecting common names, which may prove of value in the consideration of a suitable trade name:

1. The name should preferably be derived from the scientific name, representing an abbreviation, modification or translation of the meaning of the Latin scientific name.
2. No name should be chosen which is used already for a plant or plant product distinctly different in certain respects. This rule should be followed especially in case where these products are derived from plants not very closely related, belonging, for instance, to different genera or families.
3. Preferably the name should indicate or suggest the specific characters of the product.
4. The statement of the country of origin is often useful, although the importance has decreased with extent of cultivation.
5. The selection of a term adaptable to international use appears advisable.
6. The name should be rather short, easy to spell and remember.

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[2] In *J. Amer. Pharm. Assoc.*, Vol. ix, No. 7, July, 1920, pp. 671–676.

After discussing a number of new terms, based on these rules and given to products which have recently come on the market, the conclusion is reached that a great number of botanicals have been reported to be valuable for one disease or another. These have been given different common names in different localities, names too often not descriptive and not definite. Instances have been observed where plants, evidently very closely related, have been classified in different genera, if not families; and *vice versa,* where plants have been thrown together, because characteristics observed by a superficial study suggested closer relationship than existed.

The task ahead is to utilize the broader training given to-day to botanists, chemists, pharmacologists, and especially pharmacists, and bring about a further improvement of the science which has to do with the proper classification of our botanicals, based on floral characteristics, but preferably on general morphological, anatomical, chemical, and physiological characteristics. The common trade name then established on the basis of the scientific identification and certain rules agreed upon should do away with many loose terms which are still in common use, or are apt to become popular by misapplication, causing confusion, mistakes, and difficulties of varying consequence.

Technical Notes, Forest Products Laboratory.—The following items are abstracted from the bulletin dated October 15, 1920.

Charring Does Not Preserve Wood.—Tests show that the charring of fence-posts and telegraph poles so long practiced, does not appreciably delay the rotting, in fact, in the experiments, the charred posts decayed more quickly than the uncharred. Theoretically, such treatment should have a preservative action, as charcoal is not subject to the action of living organisms or ordinary oxidation, but the covering is by no means complete. If posts are seasoned before being charred, the charring does not reach the bottom of the season checks, and if charred before seasoning, the covering will open in places as the seasoning occurs. Thus, in either case, the uncharred interior of the wood may become a prey to the destructive agencies. Charring deep enough to accomplish any good weakens the post too much.

Paper From Veneer Waste.—The waste from veneer factories seems to be a valuable source for the manufacture of a high-grade pulp. The cores of many kinds of woods now used only for fuel would be suitable, and, in addition, the clippings and smaller waste amounting to about 20 per cent. of the product could be used. Among the woods thus applicable are: red gum, yellow poplar,

cottonwood, birch, tupelo, basswood, and beech. Many veneer factories are within shipping distance of pulp mills, and in other cases the factories are so grouped that it would be commercially profitable to erect a pulp mill to deal with their waste.

Preventing Decay of Mine-timbers.—Great quantities of valuable timber are being placed in the mines of the nation without any protection against decay. Experiments showed that timbers treated with coal-tar creosote installed in an Alabama mine remained sound for ten years, while all the untreated ones had to be removed. Four-fifths of the treated timbers were still good. Creosote is the most effective preventive of decay, but is objectionable on account of the fire-risk. Sodium fluoride and zinc chloride are odorless, and possibly diminish the fire-risk. They are cheaper than creosote and may be injected by the steeping, open-tank, or pressure methods. The saving is so marked that it will be profitable for all mines to use some process.

Water Solubility a Necessary Property of Wood Preservatives.— Every substance used for wood preservation must be sufficiently soluble in water to produce a toxic solution, but with very poisonous substances this solubility need not be great. In some cases a solubility of one per million is enough. The two mineral preservatives generally noted, sodium fluoride and zinc chloride, are freely soluble in water, but the creosotes are but sparingly soluble as a whole. It appears, however, that some of the ingredients of the creosote oils are sufficiently soluble to render the water toxic. The non-toxic oils are said to act as reservoirs of the toxic ingredients and feed them out slowly to the wood. Some speculations have been indulged in as to the difference between the several forms of preservatives due to the difference of solubility.

H. L.

Phosphotungstic Acids and Phosphomolybdic Acids.—HSIEN WU of the Harvard Medical School has made an elaborate study of these two groups of complex organic acids (*Jour. Biol. Chem.*, 1920, xliii, 189–220). For each of these complex acids, two series exist; the ratio of the phosphoric anhydride to the molybdenum trioxide (or tungsten trioxide) is 1 : 18 in the one series, and 1 : 24 in the other series. The uric acid reagent and the phenol reagent, which are used in the colorimetric determination of these respective compounds, contain complex acids in which the ratio is 1 : 18. Two phosphotungstic acids belonging to the 1 : 18 series have been prepared, and probably are isomers. The phosphomolybdic and phosphotungstic acids may also be used in inorganic analysis, for the detection of copper, the detection and colorimetric determination of phosphoric acid, as an internal indicator in oxidation and reduction reactions, and for similar determinations.

J. S. H.

NOTES FROM THE U. S. BUREAU OF MINES.[*]

MANUFACTURE OF SULPHURIC ACID IN THE UNITED STATES.

By A. E. Wells and D. E. Fogg.

SULPHURIC acid is one of the most important of all chemicals, not only because of the large quantities manufactured, but also because of the wide use of the acid in many different industrial works. The more important uses are as follows:

Dilute acid—that is 60°B. (78 per cent. H_2SO_4) acid, or weaker, is used in the manufacture of superphosphates, ammonium sulphate, and sulphates of metals; in precipitating barium and calcium sulphate for chemical purposes; in the manufacture of mineral acids; in pickling sheet iron for tinning and galvanizing; in various metallurgical operations; in the production of copper, zinc, nickel, silver, and gold; in the manufacture of galvanic batteries, storage batteries, electroplating, ether, organic coloring matters, starch, sirup, and sugar; and in innumerable other chemical and industrial operations.

Concentrated acid—that is, 78 per cent. to 100 per cent. H_2SO_4—is used for purifying benzene, petroleum, paraffin oil, and other mineral oils; for manufacture of nitroglycerin, pyroxylin, nitrobenzene, picric acid, and various other nitric compounds and nitro ethers; and in the manufacture of fatty acids by distillation.

Fuming acid (oleum) is used principally for the manufacture of explosives, such as nitrocellulose, trinitrotoluol, picric acid, and nitroglycerin; manufacture of certain organo sulphuric acids; and for fortifying weaker acids.

When the United States entered the war, heavy requirements for explosives manufacture made necessary a definite knowledge of the sulphuric acid capacity of the country. The Bureau of Mines, under the authority conferred by the explosives act, made a complete survey of the sulphuric acid situation. Data were collected on the situation and capacities of the various acid plants,

sources of supply of raw materials, the principal points in regard to manufacturing processes, and the uses of the acid.

Bulletin 184 of the Bureau of Mines, entitled " The Manufacture of Sulphuric Acid in the United States," by A. E. Wells and D. E. Fogg, is a comprehensive report on the results of the investigation.

DETERMINATION OF WATER IN PETROLEUM EMULSIONS.

By E. W. Dean and W. A. Jacobs.

THE BUREAU OF MINES has recently developed an improved method of determining water in petroleum emulsions, the improvement consisting chiefly in the use of apparatus more convenient than any hitherto employed. The method has been used in the bureau's laboratories, as well as in a number of commercial laboratories with marked success, not only for determining the water content in heavy fuel oils, but also in tars, and in mixtures of powdered coal, oil, and water. A description has been published in the *Journal of Industrial and Engineering Chemistry* (Vol. 12, May, 1920, p. 486).

As the bureau has received various requests regarding sources of the apparatus used, it has taken steps to render the method available for general use.

Arrangements have been made so that the glassware and particularly the " distilling tube receivers " employed in the new method can be readily purchased from any one of several chemical supply houses.

The special electric heater designed and used by the bureau cannot be obtained in the market. Directions for making this heater have been published (*Journal Ind. and Eng. Chem.*, Vol. 10, Oct., 1918, p. 823), but many laboratories are not in position to construct such a heater, and many laboratories that are otherwise in position to do so, cannot purchase nickel-chromium wire, due to patent restrictions. Recent experiments by the writers have shown that an ordinary electric hot plate converted into a sand bath makes a usable substitute for the special heater. Also, it has been determined that either of two alloy compositions available for general purchase is a usable substitute for the nickel-chromium composition formerly employed in the heater. Fuller details are given in a recent report issued by the bureau.

EXPERIMENTAL SEPARATION OF LIME IN DOLOMITE.

By R. T. Stull.

In the dead burning of dolomite, for the preparation of fire resistant brick or other use the lime content is a hindrance to dead burning. The Bureau of Mines, at its ceramic experiment station at Columbus, Ohio, in the course of its investigations of the properties and preparation of dolomite, is making a study of comparative methods of separating out the lime. Experiments were made with the following three methods: (1) Dolomite was calcined and immersed for one day in running water. On account of the greater solubility of CaO in water as compared with MgO, the CaO content was reduced from 58 per cent. to 35 per cent., and the MgO content was increased from 42 per cent. to 65 per cent., the recovery of lime being 50 to 60 per cent. of the total content. (2) Calcined dolomite was boiled in water, and the resulting $Mg(HO)_2$ was then separated by flotation. The concentrate contained 65 to 75 per cent. MgO; the lime recovery was about 25 per cent. (3) There was added to calcined dolomite sufficient H_2SO_4 to convert all the CaO to $CaSO_4$. The $Mg(OH)_2$ was then separated by screening. The residue contained 75 per cent. MgO; the recovery was about 50 per cent.

The Industrial Reorganization of France. (*Le Génie Civil*, July 31, 1920.)—The Ministry of Commerce has published the results of its examination of the industrial situation of France before, during and after the war. A third volume contains the program for economic and industrial expansion in France. "All its future and, it may be added, its very existence depends upon it." Before turning to the program the French reviewer remarks: "In order that the purely industrial and commercial effort may not remain sterile, it must be supplemented by a social effort directed toward the improvement of the health of the people of France and against the diminution of the birth-rate, against alcoholism, syphilis and tuberculosis."

The great industrial impetus due to the war leads to the emphasizing of four points in the alliance of Science with Industry:

1. The directing authority should be in the hands of men of high technical attainments and even of high scientific training.
2. The employment of laboratories must be extended. Though the number of industrial laboratories is growing and though there are official laboratories of great value, still it must be

admitted that France has lagged behind Germany, Great Britain, and the United States in the establishment of these essential aids to manufacturing.

3. Better means must be devised for the prompt dissemination of technical and industrial advances. It is proposed to establish in Paris the " Office central de la Documentation."

4. Scientific Management of Factories should be the rule. The methods of Taylor are placed in the forefront.

M. Fleurent makes the interesting proposal that a State Council of Industry be instituted on which there shall be representatives of science, technology, industry, commerce, foreign trade, of workmen's organizations, of the law and of some governmental departments.

The relation of education to industry receives much attention. While the primary education of France merits nothing but praise, it is held that reforms are needed in the upper schools. The age of admission to such schools should be lowered so that young engineers might get to work at an earlier age. It is suggested that representatives of industry should sit on the highest educational council. Admirable provisions are suggested for the training of apprentices, of engineers, of business men and of farmers.

In the matter of the payment of workmen the giving of bonuses is recommended. " To the unskilled or unconscientious workman this method secures a minimum of wages depending on the time he spends at his work. The able worker can claim a considerable addition to his wages, if he is willing to avail himself of means of increasing his production."

This report, made by men of acute and analytical minds under the constraint of an imperative national necessity, is worthy of careful consideration by the industrial leaders of other countries.

G. F. S.

Bone black and decolorizing carbons are discussed by W. D. HORNE (*Jour. Ind. and Eng. Chem.*, 1920, xii, 1015–1017). The action of bone black is in part chemical, in part physical. The absorption of colors is essentially a mechanical or physical phenomenon. Bone black is used in filters 20 feet deep; 100 pounds of bone black will remove from a solution of 100 pounds of raw sugar about 25 to 35 per cent. of the ash, about 35 to 45 per cent. of the organic impurities, and about 75 per cent. of the color. With the rapid increase in the price of bone black, attempts have been made to find a substitute. Mineral matters, like fuller's earth or fragments of brick, have been impregnated with gelatin or molasses, then burned in kilns. Or vegetable matter, such as sawdust, has been impregnated with inorganic substances, then intensely heated, usually in the presence of steam.

J. S. H.

THE FRANKLIN INSTITUTE.

(Proceedings of the Stated Meeting held Thursday, October 20, 1920.)

HALL OF THE FRANKLIN INSTITUTE,

PHILADELPHIA, October 20, 1920.

PRESIDENT DR. WALTON CLARK *in the Chair.*

Additions to membership since last report, 15.

Reports of progress were presented by the Committee on Library, and the Committee on Science and the Arts.

Mr. Coleman Sellers, Jr., Vice-President of the Institute, was recognized. He gave a brief account of the life and work of Dr. Joseph Priestley and presented to the Institute for its collections an air pump once the property of Doctor Priestley.* On motion of Dr. A. S. Cushman, duly seconded, the thanks of the Institute were extended to Mr. Coleman Sellers, Jr., and Mr. Horace Wells Sellers, the donors.

Doctor Hoadley was then recognized, and presented Mr. Edward Payson Bullard, Jr., of Bridgeport, Conn., to whom had recently been awarded the Howard N. Potts Medal for his Mult-Au-Matic machine. Doctor Hoadley said:

" *Mr. President:*

" One of the important functions of The Franklin Institute is that of granting recognition to inventors who have succeeded in putting into practical operation an invention that is of service to man.

" The investigations, required to determine who among the legions of inventors are worthy of such recognition, are put by the Institute, into the hands of the Committee on Science and the Arts.

" This Committee is composed of sixty members, each of whom is of wide experience and has expert knowledge in some scientific or technical field.

" Whenever an invention, that promises to be of sufficient merit, comes to the attention of the Committee, it is referred to a Sub-Committee on New Subjects and Preliminary Examination for consideration and if it meets with the approval of this Sub-Committee it is recommended to the General Committee for investigation. On being accepted, a Sub-Committee of investigation is appointed, consisting of members who are especially qualified to make an investigation in the field covered by the invention.

" This takes into account the originality of the invention, the soundness of the scientific and mechanical principles upon which it is founded and its success when put into practical application.

" Recognizing the value of the work done by the Committee on Science and the Arts, former members of the Institute have placed at its disposal certain funds from the income of which medals can be provided for inventions of especial merit.

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* Mr. Sellers' remarks will appear in the next number of the JOURNAL.

"A little less than a year ago an invention of Mr. Edward Payson Bullard, Jr., was brought to the attention of the members. This is a mechanical device, the purpose of which is to increase the rate of production in the manufacture of parts of machines that are made in quantity.

"The fundamental idea of this invention is that of a multiple lathe, the operating parts of which are placed at equal intervals around a central vertical axis. The metal blanks from which the finished parts are to be made are firmly clamped upon pedestals that surround the central axis. These pedestals are rotated at speeds that are predetermined as required. Placed vertically above each pedestal is a tool carrier that clamps the required cutting tools.

"At the first station of this machine the finished work is removed and the new blank is inserted. When this is done the pedestals revolve bringing the blank to station 2, where a certain part of the work is done. The next movement of the pedestals brings the work to station 3, where further work is done. In this way the blank is brought successively under the different tools, and on reaching the last station it has become a finished product. To invent such a machine and to bring it to its present state of perfection in which it automatically turns out duplicate parts at a high rate of production has required years of intensive application in design, in testing and in modification, and to secure the correlation of all the operations required has called for a high degree of mechanical skill and ingenuity.

"The Sub-Committee of investigation closes its report with these words: 'For the originality and completeness with which this machine has been developed, for its adaptability to a large class of work, and for its economic value on account of its productiveness per man, per hour, per square foot of floor space, we recommend the award of the Howard N. Potts Gold Medal to Edward Payson Bullard, Jr., of Bridgeport, Connecticut, for his Mult-Au-Matic Machine Tool.'

"I have the honor to present Mr Bullard, the inventor of the Mult-Au-Matic."

The President presented the Medal and Certificate to Mr Bullard, who thanked the Institute for the honor conferred upon him.

Joseph S. Ames, Ph.D., LL.D., Director of the Physical Laboratory, The Johns Hopkins University, Baltimore, Md., then presented the paper of the evening, entitled "Einstein's Principle of Relativity and Its Bearing Upon Physics." It was shown that Einstein has introduced into the interpretation of the phenomena of nature, as observed on the earth, an entirely new concept and an entirely new method of approach. An account was given of his method and attention was called to some of the conclusions obtained by it and to their verification by experiment and observation. Especial emphasis was laid on the fact that Einstein has developed a method and not a theory. After a discussion of the subject the thanks of the meeting were conveyed to the speaker.

Adjourned.   R. B. Owens,
                                                            Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

*(Abstract of Proceedings of the Stated Meeting, held Wednesday,
October 6, 1920.)*

HALL OF THE INSTITUTE,
PHILADELPHIA, October 6, 1920.

MR. CHARLES PENROSE *in the Chair.*

The following reports were presented for final action:

No. 2751 : Radojet Air Pump. The Edward Longstreth Medal of
Merit to Messrs. Gottdank L. Kothny and Robert Suczek, both
of Philadelphia.

No. 2754 : The Work of W. L. R. Emmet. The Elliott Cresson
Medal to Dr. W. L. R. Emmet, of Schenectady, New York.

The following report was presented for first reading:

No. 2753 : Hite's Process of Sterilization by Pressure.

R. B. OWENS,
Secretary.

SECTIONS.

Electrical Section.—A meeting of the Section was held in the Hall of the
Institute on Thursday evening, October 14, 1920. Mr. Charles E. Bonine in
the Chair.

Major J. O. Mauborgne, of the Signal Corps, U. S. Army, presented a
communication on " Resonance Wave Coils for Radio Transmission and Recep-
tion." Consideration was given to the use of the resonance wave coil as a
complete antenna system, including the antenna proper, the tuning elements
associated with it and the ground or counterpoise. Various forms of resonance
wave coils for reception were shown, as well as the action of the electro-
magnetic waves of the incoming signals on the wave coil. The question of
the position of potential loops for various wave lengths was discussed. The
various forms of detector circuits used and method of coupling same to wave
coil were described. The directive properties of the resonance wave coil were
pointed out. Some consideration was also given to duplex and multiplex recep-
tion, as well as the use of the device as a wave-meter. The subject was illus-
trated by lantern slides and numerous practical demonstrations given with the
assistance of Captain Guy Hill, co-inventor of this system, and Major L. M.
Evans, of the Signal Corps. Discussing the paper, Dr. Louis Cohen, of
Washington, D. C., outlined some further probable early developments in the
use of resonance wave coils. On motion, duly seconded, a vote of thanks was
tendered to the speaker and his associates for the paper and demonstrations.

Adjourned.

R. B. OWENS,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, October 13, 1920.)

RESIDENT.

Mr. Merritt H. Adams, Vim Motor Company, 23rd and Market Streets, Philadelphia, Pennsylvania.

Mr. Evan Morgan Clymer, 142 East Fishers Avenue, Olney, Philadelphia, Pennsylvania.

Mr. Robert Lee Jickling, National Aniline and Chemical Company, Marcus Hook, Pennsylvania.

Mr. Alger L. Ward, Seventh Floor, 319 Arch Street, Philadelphia, Pennsylvania.

NON-RESIDENT.

Mr. Hunter C. Phelan, 651 Salem Avenue, Dayton, Ohio.

Mr. Frederick N. Williams, Massachusetts Oil Refining Company, East Braintree, Massachusetts.

ASSOCIATE.

Mr. Elmer Smalling, Jr., 2939 North Camac Street, Philadelphia, Pennsylvania.

Mr. Frank L. Wright, Atlas Ball Company, 4th and Glenwood Avenue, Philadelphia, Pennsylvania.

CHANGES OF ADDRESS.

Mr. Jos. H. Burroughs, 664 Bullitt Building, Philadelphia, Pennsylvania.

Mr. M. J. Caples, 701 Stockley Gardens, Norfolk, Virginia.

Lieutenant John C. Cornelius, Jr., 420 West Price Street, Germantown, Philadelphia, Pennsylvania.

Mr. Charles Henry Davis, Bass River, Cape Cod, Massachusetts.

Mr. Fred Denig, 2152 14th Street Troy, New York.

Mr. Gano Dunn, 20 Washington Square, New York City, New York.

Mr. Clarence P. Fowler, 107 Elmwood Avenue, Narberth, Pennsylvania.

Mr. Louis A. Ferguson, 72 West Adams Street, Chicago, Illinois, Box 767.

Mr. R. E. Gillmor, 72 Westmont Boulevard, Montreal, Canada.

Mr. Jacob Hasslacher, Suite 2, 70 Westland Avenue, Boston, Massachusetts.

Mr. Rudolph Hering, Spencer Arms, 140 West 69th Street, New York City, New York.

Dr. David W. Horn, 616 Montgomery Avenue, Bryn Mawr, Pennsylvania.

Mr. Lionel F. Levy, 220 West Roberts Avenue, Philadelphia, Pennsylvania.

Mr. Max Levy, Lenox Apartments, 13th and Spruce Streets, Philadelphia, Pennsylvania.

Captain Chester Lichtenberg, 136 Waverly Place, Schenectady, New York.

Mr. F. MacMurphy, 542 West 112th Street, New York City, New York.

Major C. W. McMeekin, 2218 Roosevelt Avenue, Berkeley, California.

Mr. B. B. Milner, 141 East 44th Street, New York City, New York.

Mr. Ralph H. Muller, 1209 Rush Street, Philadelphia, Pennsylvania.

Mr. H. H. Platt, Scarsdale, New York.

Prof. I. M. Rapp, State University, Missoula, Montana.

Mr. Edward Rittenhouse, Glen Loch, Chester County, Pennsylvania.

Mr. Chas. E. Rilliet, 4100–06 South Vermont Avenue, Los Angeles, California.

Mr. Joseph B. Rohrman, care of H. E. Grau, Glenolden, Pennsylvania.

Mr. William Sartain, 140 West 57th Street, New York City, New York.

Mr. Lewis K. Silcox, 7249 Cloes Avenue, Chicago, Illinois.

Mr. H. B. Spencer, President Fruit Growers Express Company, Munsey Building, Washington, District of Columbia.

Mr. Ernest Stutz, 1705 Hope Street, S. Pasadena, California.

Mr. Edw. H. Tait, 401 Brighter Apartments, 2nd and Penn Streets, Reading, Pennsylvania.

Mr. J. R. Watkins, care of J. W. Darling Lumber Company, Cincinnati, Ohio.

Mr. Earl H. Weltz, Box 597, Penn's Grove, New Jersey.

Mr. J. D. Williamson, Jr., Latham Park, Oak Lane Post Office, Philadelphia, Pennsylvania.

Mr. J. Clifford Wilson, Room 205, 1509 Arch Street, Philadelphia, Pennsylvania.

Mr. Howard Sellers Worrell, 100 East Montgomery Avenue, Ardmore, Pennsylvania.

NECROLOGY.

Mr. Henry J. Hartley, 1624 Oxford Street, Philadelphia, Pennsylvania.

Mr. R. L. O'Donnel, Pennsylvania Railroad Company, Pittsburgh, Pennsylvania.

Mr. Simon I. Kohn, 720 Market Street, Philadelphia, Pennsylvania.

LIBRARY NOTES.

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BOOK NOTICES.

METEOROLOGY. By R. G. K. Lempfert, M.A., C.B.E., Assistant Director of the
Meteorological Office. 12mo, 183 pages, contents, 48 illustrations and dia-
grams and index. London, Methuen & Co., Ltd. 7s. 6d. net.

The problem of the weather has been studied from the earliest times,
but it is practically within the memory of persons now living that it has
been dealt with in a scientific manner. This phase began as with most
sciences, by isolated observations by volunteer workers, but by degrees
the greater nations perceived the value of such data, and hence today we
have in these nations well-organized weather departments, that are not
only collectors of data and students of atmospheric phenomena, but
actively in the prophetic fields, publishing daily, or even more frequently,
forecasts of the weather.

The book in hand is by an official of the British weather office, and
presents in a compact form the leading features of observation and fore-
cast as carried out in Great Britain. In normal times, the nations of
western Europe interchange observations, and are thereby able to give
more satisfactory information to their respective inhabitants. The many
diagrams with which the book is provided serve to make clear the methods
generally pursued, the main work of the central office being to interpret
the data of the map. A very interesting map is that of the condition
around the British Isles on February 17, 1915. This shows the " cyclone,"
" depression " or " low " condition, in which the lowest pressure is indi-
cated southwest of Ireland, the " high " being in East France. These
conditions showed that if a shifting of the low occurred toward the north-
east, heavy weather would develop soon in the neighborhood of Denmark.
German observers being prevented from getting the information to the
west, and having an " anticyclonic " condition in their own area, assumed
that it would be safe to make an air raid, and, accordingly, sent out two
ships, which were shortly afterwards wrecked on the Danish coast.

The methods of making observations with the several standard instru-
ments employed by meteorologists are described at some length, a chapter
is devoted to the origin of changes in pressure, another to the tropical
revolving storms and tornadoes, and the final chapter to the composition
of the atmosphere. In the last chapter a paper by Humphreys is quoted
in which figures are given showing that at high levels free hydrogen con-

stitutes a large part of the atmosphere. Chapman and Milne, however, have recently challenged this view and take the ground that helium is the predominating ingredient at the high levels, such as 150 kilometres.

Those who desire to know about the present development of the important science of the weather will find the book very useful.

HENRY LEFFMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 84, Data on the Design of Plywood for Aircraft. Preprint from Sixth Annual Report. 15 pages, illustrations, plates, quarto. Washington, Government Printing Office, 1920. In this report are given the results of investigations made by the Forest Products Laboratory of the U. S. Forest Service at Madison, Wisconsin, for the War and Navy Departments. Sufficient discussion on the mechanical and physical properties of plywood is included so that the data may be intelligently used. The data, although primarily intended for aircraft design, have a broader field of application.

Report No. 92, Analysis of Wing Truss Stresses. 20 pages, illustrations, quarto. Washington, Government Printing Office, 1920. This report is concerned with the analysis of the effect of redundancies, and particularly of the external drag and stagger wires. The stresses in a typical training machine have been worked out for several conditions of flight, the method of least work having been applied, as an illustrative case. The chief conclusions reached are that the use of more than one external drag wire on each side is wasteful and undesirable, that the effect of the stagger wires in speed diving is important and serves to reduce greatly the load in the lift trusses, and that the advantages in reduction and uniformity of stresses to be gained from the tensiometer in practical rigging are great enough to justify the general introduction of that instrument. In particular, the stress wires are usually set up much too tightly.

Melted Basalt. (*La Nature*, October 2, 1920.)—This volcanic rock is hard to shape with chisel and hammer. Doctor Ribbe in Auvergne has, however, found that it may be melted and molded with no great difficulty by working at about 1300° C. In his preliminary experiments he obtained a glassy substance, but, fortunately, he has been able to apply a devitrifying process, which restores the crystalline structure of the original rock. The melted rock is superior to the natural basalt in resistance to wear and scratching. It is in consequence valuable for paving, for curb-stones and for stairs. This property added to the exactitude of form and dimension achieved in the process of molding points to extended usefulness in building.

Acids do not attack the melted basalt, it is claimed, and it can be used for vats, etc., in the manufacture of chemical products. It is an excellent electrical insulator and metallic posts and fittings are fixed in a very satisfactory way by inserting them in the basalt while it is still pasty.

G. F. S.

CURRENT TOPICS.

Motor Fuels.—The problem of increasing the supply of volatile fuels for internal combustion engines still presses heavily upon the world, giving rise to active exploration of areas and to investigations into the artificial production of such materials. It seems probable that the competition between several of the great nations for the control of existing or possible oil fields will be one of the most disturbing influences on the peace of the world. Already British authorities are claiming a large share in the control of such supplies. However, attention is being strongly directed to artificial fuels, among which alcohol is prominent. Alcohol has several advantages as a motor fuel; it is without offensive odor, is perfectly combustible under simple conditions, and the fire-risk is much less than that of the common petroleum and tar products. In a sense, the supply is inexhaustible, and production not subject to monopoly by any one of the great nations for it is obtainable from any vegetable containing starch or sugar, and by means of special methods even from cellulose.

The British Fuel Research Board has just issued a pamphlet in which the serious problems of supply of motor fuel for British uses is discussed at some length. It appears that in 1919 the world's production of crude petroleum was nearly 20 billions of U. S. gallons of which the United States contributed about 74 per cent. The consumption, however, exceeded the production. The lighter portions of petroleum are used for air and road transport. As England imports almost all of this class of fuel, it is obviously a very important matter for that country to obtain control of a large supply. Benzene (from coal-tar) is suitable, and as this is easily obtained from coal, attention has been directed to improving the yield. Inasmuch as coals yielding large amounts of volatile hydrocarbons are abundant in many parts of the world, the development of this source of motor fuel is well worth the attention of research chemists.

The report states that so far as alcohol production is concerned, the area included in the United Kingdom, that is, British Isles, cannot be made to yield sufficient starch- or sugar-bearing plants to solve that phase of the problem. Of course, the British Empire is a different matter, especially in view of the enormous areas that have been acquired by the settlement of war, but production in distant colonies involves protection by a navy in war time, and in peace and war an expense of transportation. The alcohol question is complicated in all countries by the social relations of alcohol, and its use as basis of revenue by taxation, so

753

that even if it was the best of fuels its manufacture will be complicated by official supervision.

The conclusions that the British authorities give in the report under consideration are as follows:

Coal is the largest as well as the cheapest source of fuels for transport purposes.

Means are already at hand for " sorting out " the potential energies of coal into forms of different availability and value.

The more volatile products, such as benzene, are so relatively costly that they ought to be used only for air transport or the lighter and swifter forms of road transport.

Town gas and coke-oven gas are applicable, and it seems practicable to use these in city and suburban traffic if light and safe containers could be constructed and stations established at which the supply could be replenished.

By carbonization at about 600° C., gas of twice the usual calorific values of ordinary gas is obtainable and the coke is a tarless, smokeless fuel, easily lighted and free burning. The cost per thermal unit by these latter methods will be far less than the cost with gasoline at present prices.

<div style="text-align:right">H. L.</div>

An Extension of the Balmer Series of Hydrogen and Spectroscopic Phenomena of Very Long Vacuum Tubes. R. W. Wood. (*Proc. Royal Soc.*, No. A 687.)—The light from hydrogen in the sun shows a series of lines no less than thirty-two in number, which follow Balmer's law. The light from the same gas in a vacuum has hitherto been made to yield on the first twelve lines of the series. In the present investigation a tube about 2 m. long and 7 mm. in diameter was used. A length of 40 cm. was straight. From each end of this portion of the tube a stretch of 80 cm. was bent away sidewise and at the distant end an electrode was fixed. The light from the straight part of the tube was used for the observations and the tube was placed end-on with respect to the spectroscope, so that the entire 40 cm. might contribute light. When the discharge was traversing the tube the color was bluish-white for about 50 cm. from each electrode, " while the straight portion is of a fiery purple, of an intensity which is almost painful to the eyes." An alternating current was used.

Professor Wood succeeded in photographing the series of lines as far as the twentieth, whose intensity he estimates to be probably less than one-millionth that of the alpha line of hydrogen. He remarks that " the experiment led to the discovery of a most remarkable type of tube and a wholly new set of spectroscopic vacuum-tube phenomena. It is probable that a quite new field is opened up for the separation and study of compound spectra."

<div style="text-align:right">G. F. S.</div>

The Blue Sky and the Optical Properties of the Air. LORD RAYLEIGH. (*Nature*, July 8, 1920.)—In a lecture on this subject delivered at the Royal Institution, May 8, 1920, the present Lord Rayleigh presents the explanation of the blue of the sky which we owe to his distinguished father. When light passes through the atmosphere, it is acted on by the molecules of the gases present. The longer waves pass through with little change, so that the transmitted light is rich in red and yellow. Thus the vivid colors of sunrise and of sunset are accounted for. The short waves, on the other hand, are scattered laterally and in this way blue light comes from the group of illuminated molecules. Soapy water or dilute milk is yellowish by direct light but appears bluish when viewed from the side.

A thick layer of ozone absorbs such wave-lengths of the light that traverse it that the emerging light is blue. This has led to the theory that this gas is responsible for the blue of the sky. No doubt it may contribute in a slight degree to the effect, but that it is not the predominating cause is shown by the redness of sunsets. At this time of day the length of the path of air traversed by the light is at a maximum and the absorption by ozone is likewise at its maximum, but the colors we see are by no means blue. Nor can absorption by ozone account for the polarization of light from the sky.

Ozone does, however, leave its hall-mark on the light which reaches the earth from the sun. The lecturer, to prove this, showed the following experiment, never before exhibited to an audience. By means of lenses and prism of quartz the spectrum of light from an iron arc was formed. The presence of the ultra-violet spectrum was demonstrated by placing a screen of barium platinocyanide beyond the violet end. The ultra-violet rays made this glow with green light. A glass tube six inches long was put in the path of the light before it was dispersed. When oxygen that has passed through an ozone generator flowed through the tube then that part of the spectrum due to the light coming through the tube was seen by the audience to lose most of its ultra-violet part. This again appeared when oxygen alone flowed through the tube. The gas from the ozone generator has less than 1 per cent. of this constituent in it, yet it cuts off the spectrum at about 2900 angstroms. The spectrum of sunlight shows the absence of the same wave-lengths. Detailed comparison of the spectrum of sunlight after it has passed through the atmosphere of the earth with the spectrum of the light of the iron arc after traversing a body of ozone shows that the absorption bands are the same in both cases and the conclusion is justified that the brevity of the ultra-violet spectrum of sunlight is due to absorption by ozone in the atmosphere.

There is scarcely any ozone near the surface of the earth. This was proved by the examination of light from a terrestrial

source after it had passed through four miles of air. There was no evidence of absorption due to ozone.

The tenuous ozone of the upper air, little known and inaccessible as it is, plays an important part in the life of man by abstracting from the sunlight the ultra-violet rays which the human eye could not endure.

In *Nature*, July 22nd, J. N. PRING speaks of a method he has devised for the determination of ozone and for discriminating it from oxides of nitrogen. He finds that at an altitude of 10,000 feet the atmosphere contains five millionths by volume of ozone. No increase in the content was discovered in passing from 4 km. to 20 km. At the Mosso Laboratory on Monte Rosa, altitude 15,000 feet, only one millionth of the volume of the air was ozone.

G. F. S.

Nitrate Content of Potable Water.—M. STARR NICHOLS of the University of Wisconsin (*Jour. Ind. and Eng. Chem.,* 1920, xii, 987–989) has determined the nitrate content of 808 samples of water which were found to be safe on bacteriological examination; 87 per cent. of the 446 samples from deep or drilled wells, 74 per cent. of the 250 samples from shallow or dug and driven wells, 77 per cent. of the 71 samples from springs, and all of the 28 samples from lakes, and 13 samples from rivers did not contain more than five parts of nitrate nitrogen per million. It is concluded that a potable water, which contains five or more parts of nitrate nitrogen per million, be considered a potentially dangerous supply until a sanitary survey has been made. This constituent should be determined in every examination of a ground water.

J. S. H.

Helium in Canada.—The studies of Dr. J. C. McLENNAN of the University of Toronto (*Canadian Chem. Jour.,* 1920, iv, 253–254) show that the natural gas of Canada contains varying amounts of the rare gas helium, which is of great value as a substitute for hydrogen in aeronautics, especially in warfare. The gas from some fields has a helium content of 0.34 per cent. Helium of a purity of 87.90 per cent. has been extracted from the natural gas; and it is apparently possible to obtain in this way helium of 97 per cent. purity with an efficiency of 80 per cent., at an estimated cost of less than two and one-half pence per cubic foot. Canada is the only part of the British Empire that contains helium in any worth-while quantity.

J. S. H.

Journal

of

The Franklin Institute

Devoted to Science and the Mechanic Arts

Vol. 190	DECEMBER, 1920	No. 6

THE CHEMISTRY OF THE EARTH'S CRUST.*

BY

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INTRODUCTION.

THE term " Crust of the Earth " is a heritage from the days when the interior of the earth was generally conceived to be a " sea of molten rock," at an enormously high temperature, covered by a relatively thin, solid crust of cooled matter. Various cogent reasons, into the consideration of which we cannot enter here, have led to the abandonment of this concept, and we now have reason to hold the following tenets as to the conditions that obtain in the earth's interior:

1. The interior is essentially—or, at least, behaves essentially like—a rigid solid, though possibly a certain amount of viscosity may be granted.

2. It is hot, but of an unknown temperature, and probably increases in temperature toward the centre, with a gradient that is unknown beyond very moderate depths, and that is probably very different in different places.

3. It is of a density greater than that of the " crust," inas-

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much as the mean density of the earth as a whole is about 5.55, while that of the crust is about 2.77, as will be shown later.

4. The earth, as a whole, acts in many respects as a magnet, and as the rocks of the crust in general are not notably magnetic, this may be attributed to the characters or composition of the interior materials.

5. From the study of the propagation of earthquakes, we are led to believe that there is a change in the physical properties at about 0.5 of the radius in depth, the matter below this not transmitting transverse vibrations. Studies on the compressibility of rocks by Adams and Williamson, in the Geophysical Laboratory, indicate that the high density of the interior cannot be explained by compressibility, so that we have reason to think that there is also, toward the centre, a change in actual substance.

6. It has been often suggested, and is more or less commonly believed, from consideration of the density and magnetic character of the earth, and from the composition of many meteorites, that part, at least, of the interior is composed essentially of iron, or of nickel-iron alloy similar to those which constitute the iron meteorites.

Leaving the interior of the earth, for the present, we may concentrate our attention on the outer shell—the so-called " crust " —which is the only portion that is directly open to our study, and which has been compared, with some justice, to a covering of slag or scoria over the interior. In dealing with this, we shall consider only its chemical characters, with, towards the end of the paper, some relations between these and the densities of rocks.

The thickness of this crust is, of course, unknown, probably not uniform, and presumably indeterminate. Following Dr. F. W. Clarke, we may assume, for purposes of computation, an approximate thickness of 10 miles (16 kilometres), this being about the (minimum) aggregate thickness of all known rocks and deposits of the various geological ages that have become exposed to our observation and study, through movements in the crust. Incidentally, it about equals the sum of the highest land elevation and the greatest oceanic depth, though no causal nexus is apparent.

This solid crust is made up almost wholly of igneous rock, that is, rock that has solidified from a hot, liquid (" molten ") condition, either as " plutonic " rocks, at different depths beneath the surface, or in the form of lava flows at the surface.

Assuming a thickness of ten miles, Dr. Clarke [1] has estimated the rock composition of the crust to be about as follows:

Igneous rocks	95.0	per cent.
Shales	4.0	per cent.
Sandstones	0.75	per cent.
Limestones	0.25	per cent.
	100.00	

Such masses as coal beds, or salt and ore deposits, are of negligible magnitude in studying the chemistry of the crust as a whole, as it is purposed to do here, though their presence is of some significance. The amount of the coating of soil is absolutely negligible from this point of view.

When we take into consideration the oceans and the atmosphere, Clarke estimates the lithosphere at 93 per cent., the hydrosphere at 7 per cent., and the atmosphere at 0.03 per cent., of the complex crust. In the following pages, however, the hydrosphere and the atmosphere, and the sedimentary rocks will not be taken into account, and we shall consider the " crust " as made up wholly of igneous rocks. This is the more justifiable, for our present purposes, because the material of the sedimentary rocks has been derived entirely, either directly or indirectly, from preëxisting igneous rocks, while the metamorphic rocks (gneisses, schists, etc.,) have been formed from either igneous or sedimentary rocks.

When we consider, then, only the igneous rocks of the earth, as a whole, we know that they are not all alike, but show wide differences in their characters, chemical and physical. There are here two main questions regarding them to be considered.

The first is: What is the average chemical composition of the igneous rocks of the crust? The answer to this is of considerable importance for the investigation of the constitution of the earth, and is also of interest in the study of the rocks themselves—the science of petrology.

The second question is: Do the igneous rocks, taken as a whole, show sensible uniformity as to general characters, or do they differ noticeably in different portions of the earth's surface? That is, is the earth's crust sensibly alike or unlike?

[1] Clarke, F. W.: " The Data of Geochemistry." *U. S. Geol. Survey, Bull.* No. 695, p. 33, 1920. The proportion of igneous rock would be still greater with greater assumed thickness of crust.

Attempts to answer these questions, with some consequences that seem to follow from their consideration, will form the chief topics of this paper.

GENERAL CHARACTERS OF IGNEOUS ROCKS.

For present purposes we cannot go deeply into the characters of igneous rocks, nor discuss them all—a subject that has produced a very voluminous literature. It is needful here to present only some of the salient and pertinent facts.

Igneous rocks, as has been said, are those that have solidified from a state of fusion, or rather liquidity, as the term fusion implies a previous solid condition. The liquid matter, that eventually solidifies as a rock, is called technically the " magma "—a term that is in frequent use in petrology.

The magma comes up from below; from what depth we do not know, though there is some reason for thinking that the places of origin are not very deep. Nor do we know whether it arises from the melting of portions of the earth that are actually solid but potentially liquid on relief of pressure, or whether it is, in general, derived from " reservoirs " of liquid magma.

The igneous magma may be compared, as it usually is, to a complex solution of salts in water. This idea, which was first suggested by Bunsen in 1861, is of great importance, and has been very fruitful in our study of the origin, formation, and characters of igneous rocks.

Among other things, it may be mentioned here that the magma contains various gases in solution, much as air is present in solution in spring water, or, rather more appropriately, as carbon dioxide is present in the waters of many mineral springs, so that it escapes on relief of pressure.

Of these gases, by far the most important, and generally the most abundant, is water vapor. This forms the major part of the clouds that are given off during volcanic eruptions, and, with other gases, produces the sponge-like structure of pumice and the cavities of vesicular lavas through expansion, caused by relief of pressure on reaching the surface. In some glassy lavas water is present to the extent of several per cent., the magma having solidified so rapidly as not to permit of its escape, and inclusions of visible water and liquid carbon dioxide are present in the crystals of many granites and other rocks. The presence of water in

volcanic magmas has been doubted by Brun and others following him, but its existence in lavas, especially those of Kilauea, has been shown conclusively by the researches of Day and Shepherd,[2] is shown by practically every rock analysis, and in other ways, so that the existence of water in magmas may be regarded as one of the established truths of the chemistry of igneous rocks.

Besides water, other gases are often present in volcanic exhalations, such as carbon dioxide, carbon monoxide, hydrogen chloride, sulphur trioxide and dioxide, hydrogen sulphide, hydrogen fluoride, ammonia, methane and possibly other hydrocarbons, sulphur vapor, hydrogen, nitrogen, or oxygen. The study of these and the bearing of their interreactions on the maintenance, and possibly the partial production, of volcanic heat, is an interesting subject.

The presence of these gases in the magma lowers its solidification point, so that a lava, on coming to the surface, may be, and usually is, liquid at a temperature considerably below the fusing point of the solid rock formed from it, during which solidification much, if not most, of the dissolved gas is lost. Either because of this, or because of the lessened viscosity, or in some other way that is not yet well understood, the gases contained in the magma seem to promote the crystallization of minerals, so that they are often referred to as " mineralizers." These gases also play an important part in the formation of many ore bodies.

The magma on solidification generally forms a mixture of minerals, substances of definite chemical composition and physical characters, just as a solution of salts in water (such as sea water), forms a mixture of crystals of salts and ice on freezing. The exception to this is when the cooling of the magma takes place too rapidly for complete, or (as with the obsidians) any, crystallization, in which case the rock is composed partly or wholly of glass. Such glassy rocks are found only as surface flows.

MINERAL CONSTITUENTS OF ROCKS.

It is a very important and striking fact that, although about one thousand different minerals are known, yet the number of the different kinds that compose by far the great majority of igneous rocks—certainly over 99 per cent. by weight of these—is very

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[2] Day and Shepherd, *Bull. Geol. Soc. Amer.*, xxiv, 573, 1913

small. Indeed, the really important and essential igneous rock-forming minerals number only about a dozen.

These essential minerals are: quartz, silicon dioxide; the feldspars, silicates of alumina and potash, soda, or lime, including the potassic orthoclase, the sodic albite, and the calcic anorthite, with isomorphous mixtures of these; the pyroxenes, metasilicates of calcium, magnesium, and iron, with aluminum or sodium in some cases; the amphiboles, in chemical composition much like the pyroxenes, but differing in crystal form and otherwise; the micas. alumino-silicates, for the most part the potassic muscovite or the potassium-iron-magnesium biotite, both containing hydroxyl; the olivines, orthosilicates of iron and magnesium; nephelite, an orthosilicate of sodium and aluminum; leucite, a metasilicate of potassium and aluminum; magnetite, ferroso-ferric oxide, often containing titanium; and apatite, a phosphate of calcium, containing a little fluorine or chlorine. Magnetite and apatite are present in almost all rocks, but seldom in more than almost negligible amounts.

Other minerals are not infrequently met with in certain types of igneous rocks, such as the silicates sodalite, hauyne, melilite, zircon, and garnet, and the oxides tridymite (a second form of silica), ilmenite, chromite, spinel, corundum, and rutile. But, considering igneous rocks from the standpoint of a study of the whole crust of the earth, these are practically negligible. Igneous rocks, then, in general, and looked at in the broadest way, are constituted almost wholly of a very few silicates of aluminum, iron, calcium, magnesium, sodium, potassium, and hydroxyl, with or without quartz (that is, excess of silica), with small amounts of a phosphate and of iron oxide, and with or without traces of other constituents. It is also to be noted that some of the essential minerals enumerated above (the pyroxenes, amphiboles, micas, olivines, and the magnetites), contain small amounts of manganese and titanium. From such a general survey of the rock-forming minerals, then, we obtain the broad lines of the chemical composition of the earth's crust as a whole.

Another important fact concerning the igneous rock minerals is that, with two exceptions, any one of them may occur in rocks with any one or more of the others. The only exceptions to this are that neither nephelite nor leucite is known to occur along with quartz, and a partial exception is that olivine seldom

occurs with quartz, and never in any large amount. Discussion of this and other relations between the various minerals would lead to a consideration of matters outside of our present scope, and would take us too far afield.

Each rock mineral may be present in very widely varying proportions—from practical totality to complete absence. We know igneous rocks that are composed entirely of quartz (arizonite), feldspar (anorthosite), pyroxene (websterite), amphibole (hornblendite), or olivine (dunite), and almost entirely of nephelite (congressite), leucite (italite), or magnetite (some iron ores). Of the essential rock minerals, only the micas and apatite do not form the whole, or almost the whole, of any igneous rock.

From totality of any one mineral we find rocks that are composed of two minerals, more that are composed of three, and still more that are composed of more than three, and with the widest possible variations in the proportions of almost all, with the exceptions noted above as to the non-coexistence of quartz with nephelite and leucite, and its rarity with olivine.

CHEMICAL CONSTITUENTS OF IGNEOUS ROCKS.

From what has been said it would appear that the various oxides (in terms of which the chemical composition of rocks is usually formulated) may be present in widely different amounts; and, within limits, this is found to be true. All of the constituent oxides have very considerable quantitative ranges, but these differ much with the different oxides. Their possible or recorded maxima are also very different, though in every case the minimum is reached with complete absence. These ranges and maxima will be stated later, after a brief discussion of the oxides that go to make up the igneous rocks.

Though, as we have seen, most igneous rocks are composed of but few essential minerals, and consequently of but few so-called " major " oxides, yet when we come to study them in detail we find that a very considerable number of different chemical constituents may be present in the different rocks. Altogether, about twenty-three are to be found, and are more or less commonly determined and recorded among the better class rock analyses. Indeed, as has been said by Dr. W. F. Hillebrand, the foremost analyst of rocks, " a sufficiently careful examination of these [igneous] rocks would show them to contain all, or nearly all,

the known elements, not necessarily all in a given rock, but more than anyone has yet found." Proper study, therefore, of the chemistry of igneous rocks, and their chemical analysis, if this be complete as to the determination of all the constituents probably present, is evidently a somewhat complicated matter, and one not without difficulties of various kinds.

From the many chemical analyses of rocks that have been made since this was first attempted very early in the nineteenth century, (the total number of published rock analyses now numbering about 12,000), we have a good idea of what chemical constituents make up rocks, their relative abundance, and their various ranges in percentage.

By far the most important and generally the most abundant are what are called the " major " constituents. These are nine in number and, stated as oxides, are: silica (SiO_2), alumina (Al_2O_3), ferric oxide (Fe_2O_3), ferrous oxide (FeO), magnesia (MgO), lime (CaO), soda (Na_2O), potash (K_2O), and water (H_2O).[3] Together these nine oxides make up about 98 per cent. of igneous rocks, and all of them are present in greater or less amount in practically every rock, so that the amount of each must be determined in every chemical analysis of a rock that makes the slightest pretense to good quality.

As the most abundant and essential rock minerals are either silica or silicates, and as all igneous rocks, with the exception of some rare and small iron ore bodies of magmatic origin, are consequently silicate rocks, silica shows easily the highest maximum and the widest range, both in extremes and in the usual run of occurrence. A few igneous rocks are known that are composed almost entirely of quartz,[4] and the highest silica percentages recorded for igneous rocks are 98.77 and 97.65, in rocks from the Transvaal; while one from Cumberland (England), the border facies of a granitic mass, shows 96.16, one from Massachusetts shows 93.38, and one from Arizona 92.59. In general, however, the percentage of silica ranges from about 75 to about 34, and it drops to zero only in some " magmatic " iron-ore bodies. In almost all rocks it is the most abundant constituent.

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[3] This order is not quite that of relative abundance, but that which is commonly used in the statement of rock analyses.

[4] Quartz veins are not considered here, as they are usually of non-igneous origin, at least in the commonly accepted sense.

Alumina, which is almost invariably the next most abundant constituent, reaches a maximum of about 60 per cent. in some corundum-bearing syenites from Canada and the Urals, and has a general range from about 20 to about 10. It is wholly absent only in the " magmatic " ores, and in some rocks that are composed entirely, or almost so, of olivine. The two oxides of iron reach, of course, their maxima in such rocks as the iron ores already spoken of; [5] the highest figures recorded for Fe_2O_3 being 88.41 (Sweden) and 62.39 (Ontario), while for FeO they are 34.58 (Sweden) and 32.92 (Minnesota). Their general range is from nearly 15 for each (FeO generally higher than Fe_2O_3), and but little more than that for both together in any one rock, to less than one-half of one per cent. Iron is seldom entirely absent.

Magnesia reaches its maximum in the almost purely olivine rocks (dunites) of North Carolina, 48.58, and of New Zealand, 47.38, but its general range is from about 25 to much less than 1 per cent. Lime is highest (22.52) in some pyroxenites of the Urals, and almost as high (about 20) in the anorthosites of Canada and elsewhere, but it ranges in general from about 15 to nearly zero.

Of the two alkalies, soda reaches a maximum of 19.48 in a rare rock from Canada, and of 18.67 in another from Turkestan; but its general range is from about 15 per cent. down to nearly zero. It is hardly ever entirely absent. Potash shows a somewhat smaller range than soda, its maximum being 17.94 in a recently discovered lava from Italy, the next highest figure being 11.91 from Wyoming; but in general it seldom gets above 10 per cent., ranging from that down to zero. Its amount is generally less than that of soda.

As regards water, the last of the major constituents, a few volcanic glasses are known which, although perfectly fresh and undecomposed, contain up to 8 or 10 per cent., and there are some fresh crystalline rocks that contain from 3 to 5 per cent. Generally, however, if a rock contains more than about 2 per cent. of H_2O, this can usually be attributed to alteration, though few rocks are quite free from this constituent.

After the major come the " minor " constituents, which are

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[5] It is a question whether all of these ore bodies are to be considered as really igneous rocks, though some undoubtedly are.

almost always present in very small amounts, seldom over 2 per cent. for any one, or rarely up to 5 per cent. for all of them, in any one rock. Of these minor constituents, three are of special importance, partly because of their almost constant presence, and partly because they are generally present in largest amount. These three are: titanium dioxide, phosphorus pentoxide, and manganous oxide, and all three should be determined in a good rock analysis.

Titanium dioxide (TiO_2) reaches a maximum in some very rare rocks from Virginia (69.67 and 65.90) and Quebec (53.35), but as a general thing its percentage is seldom over 5, and is mostly from about 2 to nearly zero. Of the many rocks of all kinds that I have analyzed, there has not been a single one that did not contain titanium, in some cases in very small, but always in easily determinable, quantity. This is also the experience of Doctor Hillebrand,[6] and probably of every other experienced analyst of rocks.

The maximum for phosphorus pentoxide (P_2O_5) is but a little above 16 per cent. in some highly unusual rocks from Sweden and Virginia, that are composed largely of apatite, with titaniferous magnetite or rutile. In few rocks, however, is it above 3 per cent., and its general range is from about 1 per cent. to zero. It does not seem to be present so constantly as titanium (or manganese), as one occasionally meets with a rock that shows no trace of it, though this may be because of the more delicate tests for the other two.

Manganese, as manganous oxide (MnO), is present in practically every rock that has been analyzed, but its maximum is much lower than those of titanium and phosphorus oxides. Some, if not most, of the high figures reported for it are almost certainly due to analytical errors, and the highest recorded figures that are trustworthy are 1.90 and 1.46 in two rocks from Bahia, Brazil. Its general range is from 0.3 per cent. to about zero.

The other minor constituents that are readily determinable, and many of which are indeed determined in good analyses, are quite varied. The list is as follows: Carbon dioxide (CO_2), zirconia (ZrO_2), chromium sesquioxide (Cr_2O_3), vanadium sesquioxide (V_2O_3), the " rare earths " ((Ce, Y)$_2O_3$), nickel oxide (NiO), strontia (SrO), baryta (BaO), lithia (Li_2O), sulphur as

[6] Hillebrand, W. F.: *U. S. Geol. Survey, Bull.* No. 700, p. 25, 1919.

both sulphide (S) and sulphur trioxide (SO₃), chlorine (Cl), and fluorine (F). To these might be added boron, cobalt, copper, glucinum, lead, molybdenum, nitrogen, and zinc, which, however, are almost always present in such extremely small amount, or the analytical difficulties are so great for the separation of the small quantities in which they occur, that their determination is rarely attempted.

The maxima and ranges of some of these may be briefly stated. Carbon dioxide may be present, as a component of a few minerals (as in primary calcite and cancrinite), in some unaltered rocks; but its presence is generally due to alteration. In one calcite trachyte from Spain its amount is 7.69 per cent., and in cancrinite rocks it may reach about 1.70, the carbonate minerals in these being apparently primary. But it is generally considered as a measure of the alteration of the rock by weathering, etc.

Zirconia is much less abundant than the closely related titania and, though it reaches a maximum of nearly 5 per cent. in some Greenland rocks, in general it seldom is over 1 per cent., is usually much less, and is quite absent from most rocks. It forms, by the way, one of the most striking illustrations of the correlation of the occurrence of different elements in different kinds of rocks, as will be brought out later.

Baryta and strontia are very commonly present, though they are seldom determined in analyses made outside of the United States, Canada, and Australia. In almost every case the amount of baryta is much greater than that of strontia, this being an exception to a general rule as to the occurrence of related elements, to be mentioned later. They both reach their maxima in certain exceptional, highly potassic rocks of Wyoming, of about 1 per cent. for baryta and 0.3 for strontia; though usually baryta is present up to but a few tenths of one per cent., and strontia in hundredths.

Sulphur, as sulphides, is present up to about 9 per cent. in a peculiar, pyrrhotite-bearing rock from Maine, and probably in similar amounts in some sulphide ore-bodies of magmatic origin in Norway, which have not been fully investigated. But, as a rule, its amount is seldom over 1 or 2 per cent., and is usually in tenths of a per cent. The highest figures for sulphur trioxide are about 2.5 per cent. in rocks from Apulia and Kamerun, and somewhat lower on Tahiti, but these are exceptional, and it is usually present only in tenths or hundredths of a per cent. Much

the same can be said of chlorine, the highest figures for which are those of a rock from Turkestan (about 7), one from Quebec (4.47), and one from French Guinea (2.80). It is present in many rocks, especially lavas, but only in a few tenths or hundredths of a per cent.

Chromium sesquioxide is known to be present up to about 4 per cent. in some ores from Greece, which are probably of magmatic origin, and is reported as between 2 and 3 per cent. in some undoubtedly igneous rocks from Baden. But these are highly exceptional, and about 0.5 may be taken as its usual maximum. It is generally entirely absent. Vanadium sesquioxide is always present in much less quantity and is usually quite absent. The oxides of the rare earth metals, chiefly ceria and yttria, reach a maximum of 1.79 in a rare type of rock from Madras, 0.6 in one from Sweden, and 0.4 in one from the islet of Rockall, but the usual maximum is only one- or two-tenths of 1 per cent. They are less often determined than they should be. Nickel oxide is present in some rocks up to about 0.2 per cent. The maximum amount of each of the other minor constituents may be placed at not over 0.5 per cent., and they are almost always found only as one- or two-tenths, or still more often as hundredths, of a per cent., or are absent. Indeed, for most of the minor constituents the quantities usually yielded by analysis are so small as to be significant only as to their actual presence or absence.

A few words may be said of boron, glucinum (beryllium), and scandium, as these enter into a later phase of the subject. The analytical difficulties involved in their determination, for the extremely small amounts that are present, are so great that the percentage of none of these is recorded for any rock. Yet they are all known to be rather widely distributed among the igneous rocks, boron in tourmaline, glucinum in beryl, and both in some other rarer minerals, while the widespread occurrence of scandium among igneous rocks, though in very small amounts, has been shown spectroscopically.[7]

THE AVERAGE IGNEOUS ROCK.

We come now to the consideration of the average chemical composition of the earth's crust, that is, of all igneous rocks. Apparently Dr. F. W. Clarke was the first to undertake this

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[7] Eberhard, C.: *Sitzb. kg. preuss. Akad. Wiss.*, 1908, p. 851.

estimation,[8] basing his conclusions largely on the numerous analyses that had been made by the chemists of the United States Geological Survey. Since then he and others, Harker, Mennell, Knopf, Mead, and the writer, have published other estimates, which, it may be said here, do not differ greatly the one from the other. The latest discussion of this subject is to be found in the last edition of Clarke's " Data of Geochemistry," [9] where numerous references to the literature are given.

The true estimation of the average chemical composition of the igneous rocks is by no means such a simple matter as it may appear to be at first thought, and, before we deal with it, it will be as well to state very briefly some of the disturbing factors that are involved. The matter will be treated in greater detail in a forthcoming paper by Doctor Clarke and the writer.

In the first place, we know but little of the exact chemical characters of the igneous rocks of many districts of the earth. This is true of the great continents of Asia and South America, as well as of Africa and Australia, in all of which we have, for the most part, a knowledge only of the rocks more or less near the coasts, and know only in a general and very imperfect way the rocks that constitute the vast expanses of the interior portions. The same ignorance, either total or partial, holds true for many countries, such as China, Arabia, and even Brazil, India, Egypt, and Spain, in which the number of analyses is quite disproportionate to the number and masses of igneous rocks that are known to occur. A most striking example is furnished by the West Indies, where, of the igneous rocks of the otherwise well-known and readily accessible large islands of Cuba, Jamaica, Porto Rico, and Haiti, we do not possess a single analysis.

Most of the countries of Europe are well represented, but for the most part with not very complete analyses. North America is well known, especially as to the rocks of the United States and southern Canada. The analyses of both these countries are of exceptionally high general quality. Parts of Australia, especially New South Wales, Victoria, and Queensland, with New Zealand, are well represented, as is also British Guiana, and it should be said that the analyses of Australian and British Guiana rocks are

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[8] Clarke, F. W.: *Bull. Phil. Soc. Wash.*, xi, p. 131, 1889; also *U. S. Geol. Survey, Bull.* 78, p. 34, 1891.

[9] Clarke, F. W.: *U. S. Geol. Survey Bull.*, **695**, pp. 24 ff., 1920.

almost the only ones that, as a whole, are comparable as to accuracy and completeness with those of the United States, which holds a preëminent position through the labors of the chemists of the United States Geological Survey.

A second disturbing factor, and one that has been often advanced against the validity and representativeness of the estimates of the average composition of rocks, is that the true relative amounts of various rocks are not properly represented because of the selection of material for analysis. It has frequently happened that the petrographer has had analyzed rather the rare or most interesting rock types than those which, though much more abundant in the region described, are of more usual character. While this is often to be expected and, from a special point of view, is almost justifiable, yet it certainly may involve a serious disturbance in the estimation of the composition of the crust as a whole. This is so, because the most interesting types, often *ipso facto,* are much less abundant than the common ones, so that, as regards the relative masses of the various kinds of rocks in any given region, they are disproportionately represented. It is needless here to give examples, of which there are very many; it would lead us too far into the technicalities of petrography.

Although this objection is serious, and is entitled to consideration, yet it would seem, on detailed examination, not to be of the overwhelming character that is often attributed to it. For one thing, the satellitic rocks of the dikes and other small bodies (which are most prone to furnish " interesting " types), tend to be complementary to each other, through processes of differentiation, and so, as Doctor Clarke says, " they tend to compensation, and so to approximate to the true mean." Also, as in a number of examples from many localities that could be cited, only the main body or the most prominent types have been analyzed, chiefly because of the labor or expense of making chemical analyses of rocks. Again, as I have pointed out elsewhere, the more " basic " rocks, that is, those that are lowest in silica and highest in iron oxides, magnesia, and lime, are most liable to alteration, so that many of their analyses would be excluded from the data selected for our purpose, for which only analyses of fresh and unaltered rocks are considered.

These, and other considerations that might be mentioned, tend to minimize the rather prevalent idea that the averages, such

as have been calculated in former years by Doctor Clarke and me, are not strictly representative, in that the well-known apparent preponderance of granitic rocks is not sufficiently emphasized. Attempts have been made by some to correct such errors by weighting the average analyses of the various rock types by their areal values.[10] Such a procedure, however, is open to two objections: As much weight is thus allowed for lava flows, of manifestly small vertical extension, as for massive intrusive bodies presumably of much greater depth; and, as Clarke points out, " the surface exposure of a rock is no certain measure of its real volume and mass, for it may be merely the peak or crest of a large formation."

But the serious objection to any such attempts at correcting what may be, and often admittedly are, defects in our data, is that they introduce unduly the personal equation, and thus may, or are likely to, introduce other errors of unknown and indeterminate magnitude. As has been shown very briefly above, we are as yet in great ignorance as to the igneous rocks of a large portion of the earth's surface and crust, and it would seem to be the philosophical attitude to admit this and, as Doctor Clarke [11] says, " do the best we can with the available data." They are admittedly not ideal, but an attempt to better them, at this stage of our knowledge, is more likely than not to make a " bad matter worse." Let us be philosophical Italians for a moment, and say with them " Cï vuol pazienza."

Apart from such fundamental considerations of the character of our basal data as have been all too briefly touched on above, we meet with others when we come to consider the analyses themselves. No analyses are ideally perfect, either as to accuracy or completeness, but, while it is obviously the desirable procedure to exclude from our data rock analyses that may not be up to the ideal mark that we may set, yet, by so doing, we shall inevitably reduce the number of our data so as probably to more than offset their excellence in quality. We should have and use, of course, only analyses that are perfectly accurate and complete as to the determination of all the constituents that may be present. But— " humanum est errare," and so we must here also " do the best we

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[10] Daly, R. A.: " Igneous Rocks and Their Origin," New York, 1914, pp. 19–46, 168–170; and Knopf, A.: *Jour. Geol.*, xxii, p. 772, 1914.

[11] Clarke, F. W.: *Proc. Amer. Phil. Soc.*, li, p. 215, 1912.

can with the available data," excluding, of course, from consideration analyses that are manifestly bad. Consideration of this topic would lead us too far astray, but it will be found discussed elsewhere.[12]

It may also be mentioned here that, as some of the minor constituents are, in the course of analysis, precipitated and weighed with others, and are later determined separately and subtracted from the previous total figure, if these are not determined the figure for the main constituent will be too high. This is notably the case with alumina, with which are precipitated and weighed the oxides of titanium, phosphorus, rare earth metals, zirconium, chromium, and vanadium, with often some manganese. If the analysis is not complete as regards these constituents, therefore, the figure for alumina will be too high.

As has been said above, the average composition of the igneous rocks has been estimated by several petrologists—Clarke, Harker, Loewinson-Lessing, Daly, Knopf, Mead, and myself. Clarke based his earlier estimates very largely on the analyses of rocks from the United States, as did Knopf, while Harker's average was of rocks from Great Britain alone. In his latest estimates Clarke included rocks from all over the globe, as did I in my own computation. This also was the basis of Daly's and Mead's computations, though in both their estimates, which were founded largely on personal selection of what constituted " types " of various rocks, the personal equation enters somewhat unduly. As we shall see later, continental averages, or others selected from regional data, differ too much to be representative of the average composition of the whole " crust."

The basis for the present, and latest, estimate was the collection of rock analyses that has recently been published.[13] This includes practically all the analyses of igneous rocks, from all over the earth, that have been published between 1883 and 1913, inclusive. These amount to 8602 analyses, of which 5179 of fresh rocks were considered to be " superior; " that is, satisfactory as to accuracy and completeness. Only these 5179 analyses were used. The computations of the various averages, for the whole earth, the continents, and various districts of the earth's surface, were made by Dr. F. W. Clarke, during the sum-

[12] Washington, H. S.: U. S. Geol. Survey, Prof. Paper No. 99, pp. 10–26, 1917.

[13] Washington, H. S.: U. S. Geol. Survey, Prof. Paper No. 99, 1917.

mer of 1919. To him I am greatly indebted for his very painstaking and laborious undertaking, and would express my great appreciation of his kindness in permitting the present publication of some of his results. It must be said that there are presented here only a few of these, and that all the data in detail, with certain considerations of them, are to be published by us jointly in the near future, as a Professional Paper of the United States Geological Survey.

TABLE I.

Average Composition of the Earth's Crust.

	1	2	3	4
Silicon dioxide (SiO₂)..............	59.09	58.59	57.78	59.83
Aluminum sesquioxide (Al₂O₃)........	15.35	15.04	15.67	15.02
Ferric oxide (Fe₂O₃)...............	3.08	3.94	3.31	2.62
Ferrous oxide (FeO)...............	3.80	3.48	3.84	3.43
Magnesium oxide (MgO)............	3.49	4.49	3.81	3.74
Calcium oxide (CaO)...............	5.08	5.29	5.18	4.83
Sodium oxide (Na₂O)...............	3.84	3.20	3.88	3.37
Potassium oxide (K₂O).............	3.13	2.90	3.13	3.05
Water (H₂O)......................	1.14	1.96	1.76	1.90
Titanium dioxide (TiO₂)............	1.05	0.55	1.03	0.79
Phosphorus pentoxide (P₂O₅).........	0.30	0.22	0.37	0.29
Manganous oxide (MnO)............	0.125	0.10	0.22	0.10
Carbon dioxide (CO₂)...............	0.102	0.37	..	0.49
Zirconium dioxide (ZrO₂)............	0.039	..	..	0.023
Sulphur (S)......................	0.053	0.034	..	0.10
Chlorine (Cl).....................	0.056	0.012	..	0.063
Fluorine (F).....................	0.078	..	..	0.10
Chromium sesquioxide (Cr₂O₃)........	0.056	0.021	..	0.048
Vanadium sesquioxide (V₂O₃).........	0.032	..	..	0.026
Nickelous oxide (NiO)..............	0.025	..	..	0.026
Barium oxide (BaO)...............	0.055	0.033	..	0.10
Strontium oxide (SrO).............	0.022	0.009	..	0.043
Lithium oxide (Li₂O)..............	0.007	0.011	..	0.011
	100.000	100.250	100.00	100.000

1. Latest estimate, Clarke and Washington, 1920.
2. F. W. Clarke (first estimate). *Bull. Phil. Soc.*, Wash., xi, p. 135, 1889.
3. Washington, *Prof. Paper* No. 99, p. 108, 1903.
4. Clarke, *U. S. G. S.*, *Bull.* No. 695, p. 28, 1920.

In Table I there is given the most recent calculation of the average igneous rock, together with three of the most important of the earlier estimates. As regards No. 1, it is to be noted that the figures for the main constituents, from silica to water, inclusive, were arrived at by dividing the sums total of the various determinations by the whole number of analyses, as all of these constituents were determined in all the analyses used. For the

minor constituents, from titanium dioxide to lithium oxide, inclusive, the figures given are the means of the sums total of the various constituents divided by the whole number of analyses and also by the number of determinations. The former would presumably give a minimum, and too low an average, and the latter would probably be too high; while the mean would be probably rather nearer the true figure. This matter has been discussed by Clarke and by me elsewhere, and will be enlarged on further in our joint publication. The figures given here should be considered as provisional, as adequate discussion of their relative merits is not called for here. The figure for fluorine is almost certainly too high, as are probably those for chromium, barium, and one or two other oxides, while possibly that for carbon dioxide is a trifle too low.

From No. 1 it will be seen (and the same is approximately true of all the others), that the first nine oxides (from silica to water, inclusive), constitute 98 per cent. of the whole, and that these, with the oxides of titanium, phosphorus, and manganese, make up together 99.475 per cent. of the crust, leaving only a trifle more than one-half of one per cent. for all the other oxides.

Thus we see that in round numbers silica is the most abundant, and constitutes about six-tenths (nearly two-thirds) of the crust; alumina is next—a very poor second—slightly more than one-seventh; then the two iron oxides, together about one-twelfth; lime about one-twentieth; soda about one twenty-fifth; magnesia about one-thirtieth; potash about one thirty-third; water and titanium dioxide each about one one-hundredth; phosphorus pentoxide about one three-hundredth, and manganous oxide about one eight-hundredth, while carbon dioxide is about one one-thousandth. Each of the others is notably less than one one-thousandth. It will be observed that in the list, which includes all the constituents that may be commonly determined in really good and complete analyses of igneous rocks, neither lead, tin, zinc, mercury, silver, gold, platinum, arsenic, antimony, or several other of the elements commonly used in daily life, are represented. The only common metals shown are iron, aluminum, manganese, and nickel. This is a rather important point that will be adverted to later.

In order to form an idea of the actual rock that a magma of this average composition would form under normal conditions,

we must calculate, from the data given by the analysis, the presumable actual mineral composition, or the " mode," as it is technically called. There are two general and important conditions controlling the products of solidification that may be considered. The magma may have solidified at considerable depth, slowly and under great pressure; or it may have solidified, as a lava flow, on the surface; that is, rapidly and under low pressure. The former would furnish what is called a plutonic rock (as a granite or a gabbro), and the latter an effusive one (as a rhyolite or a basalt) ; and the different conditions of solidification would bring about certain changes in the mineral composition of the resulting rock.

Such a calculation leads to the following results, which are to be considered as only approximately correct, as variations in the mode, of slight extent but in different directions, may be brought about by slight variations in the conditions of solidification. As a plutonic rock the magma would form a so-called granodiorite; that is, a rather coarse-grained, holocrystalline rock, much like many granites (and which would be commonly called a rather dark granite), composed of feldspar, quartz, hornblende or biotite, and very small amounts of magnetite and apatite. If it solidified under surface conditions, the magma would form that most common kind of lava, an andesite, rather fine-grained, light gray or pinkish, and showing small crystals ("phenocrysts") of feldspar and either hornblende or pyroxene, with perhaps a little biotite, in a dense "groundmass." Under the microscope the groundmass would show feldspars, pyroxene (or hornblende), and possibly a little quartz, with small grains of magnetite and apatite, and with or without glass, according to the rapidity of cooling.

Stated in quantitative terms of " modal " or actual minerals, the rocks would have probably the following approximate compositions :

	Granodiorite	Andesite
Quartz	11	10
Andesine (Na-Ca feldspar)	47	47
Orthoclase (K feldspar)	16	18
Hornblende and biotite	20	} 19
Pyroxene		
Magnetite	5	5
Apatite	1	1

It will be seen that, in either case, the average rock would be composed entirely of the most common minerals, as is to be expected, with the exceptions of olivine, nephelite, and leucite, which are much less often met with and which, furthermore, are not found in rocks with an excess of silica, as is true of the average rock. Inasmuch as the average rock would have been formed at some depth beneath the surface, the average crust may be considered to be a granodiorite, with the general characters and mineralogical composition described briefly above. The fact, however, must not be lost sight of that locally the crustal rock may vary considerably, as will be pointed out later. We are dealing here only with the average of the crust as a whole.

We may examine the chemical composition of the earth's crust in greater detail and, as has been done by Clarke in the papers cited above, reduce the figures of the analysis to the form of the component elements. The results are given in the annexed Table II, there being here presented, not only the elementary constituents of the average rock given in Table I, but in addition data showing the relative abundance of some other of the more important elements that are not usually, or indeed are never, determined in the analysis of rocks. The data for these are taken from estimates by Vogt, De Launay, and Kemp, with additional data by Clarke and Steiger for a few, and some additions and changes in relative position based on my own studies. An " x " means a digit in the respective decimal place or places. The elements are presented in their order of relative abundance.

This average, it must be repeated, does not include the sedimentary rocks or contituents of the hydrosphere or of the atmosphere. Clarke has included these in several of his estimates, and his latest shows that the percentage, on this basis, of oxygen is 50.02, of silicon 25.80, of aluminum 7.30, and of the other most abundant elements in similarly slightly less amounts than in Table II. When thus reckoned chlorine and carbon fall in between titanium and phosphorus, with percentages, respectively, of 0.20 and 0.18, while nitrogen appears between chromium and zirconium with a percentage of 0.03.

Leaving these refinements out of consideration here, there are some striking features presented in the table to which attention may be called. The first is the appearance among the abundant elements of some that are usually counted as rare. Among these

TABLE II.

The Chief Elements in the Earth's Crust in Order of Abundance.

1. Oxygen 46.43
2. Silicon 27.77
3. Aluminum 8.14
4. Iron 5.12
5. Calcium 3.63
6. Sodium 2.85
7. Potassium 2.60
8. Magnesium 2.09
9. Titanium 0.629
10. Phosphorus 0.130
11. Hydrogen 0.127
12. Manganese 0.096
13. Fluorine 0.077
14. Chlorine 0.055
15. Sulphur 0.052
16. Barium 0.048
17. Chromium 0.037
18. Zirconium 0.028
19. Carbon 0.027
20. Vanadium 0.021
21. Nickel 0.019
22. Strontium 0.018
23. Lithium 0.003
24. Copper 0.002
25. Cerium, etc. 0.001
26. Glucinum 0.00xx
27. Cobalt 0.00xx
28. Boron 0.000x
29. Zinc 0.000x
30. Lead 0.000xx
31. Arsenic 0.000xx
32. Cadmium 0.0000xx
33. Tin 0.0000xx
34. Mercury 0.0000xx
35. Antimony 0.0000xx
36. Molybdenum 0.0000xx
37. Silver 0.00000xx
38. Tungsten 0.00000xx
39. Bismuth 0.00000xx
40. Selenium 0.000000xx
41. Gold 0.000000xx
42. Bromine 0.000000xx
43. Tellurium 0.0000000xx
44. Platinum 0.0000000xx

100.000

are especially titanium, barium, chromium, zirconium, vanadium nickel, strontium, and lithium, with copper, cerium, glucinum, cobalt, and boron among those to which no definite figures can be assigned as yet. Titanium occupies the ninth place among the elements (tenth among the oxides), although it is usually considered a " rare " element, and its name and existence are possibly unknown to many persons. The establishment of this fact, probably a very important one in our study of the constitution of the earth, is due primarily to the chemists of the United States Geological Survey, who, under the leadership of Dr. W. F. Hillebrand beginning in the early eighties of the last century, first began to determine the "rarer" elements in their analyses of the rocks of this country. Similarly, they found that some others of the supposedly rare elements are widely distributed, notably barium, strontium, chromium, vanadium, nickel, and even molybdenum.[14]

In Table II it is also noteworthy that, of the metals in daily and common use, only aluminum, iron, manganese, chromium, vanadium, and nickel, appear among those elements that are present in the rocks of the crust in sufficient amount to be commonly determinable by the usual processes of analysis. Such common and " every-day " metals as copper, zinc, lead, tin, mercury, silver, gold, and platinum, antimony, arsenic, and bismuth—metals that are of the utmost importance to our civilization and our daily needs—all these are to be found in igneous rocks, if at all, only in scarcely detectable amounts. Though they are ultimately derived from the igneous rocks, they are made available for our use only by processes of concentration into so-called ore bodies.

To give some concrete and striking figures, it may be pointed out that the eight most abundant elements of the earth's crust (oxygen, silicon, aluminum, iron, calcium, sodium, potassium, and magnesium)—the only ones whose amounts are over 1 per cent.—constitute together 98.63 per cent. of the crust. These, with titanium, phosphorus, hydrogen, and manganese—twelve in all—make up 99.612 per cent.; thus leaving but about 0.39 per cent. for all the other elements, among them some that are quite indispensable for our existing civilization.

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[14] Cf. Hillebrand: *Jour. Amer. Chem. Soc.*, xvi, pp. 81–93, 1894; *Amer. Jour. Sci.*, vi, p. 209 1898; *U. S. Surv. Bull.* 700, p. 24, 1919.

A cursory examination shows that the most abundant elements in the earth's crust are, on the whole, those of low atomic weight, as has been often pointed out, while the rarer ones are, in general, those of higher atomic weight. It has also been pointed out by Clarke [15] that, considering the several elements of any group in the periodic table (for which see page 780), while the first member is comparatively rare, the second is the most abundant (the oxygen group being the only exception), and the members become increasingly rare with increasing atomic weight. This is well seen, for example, in Group 1 (lithium, sodium, potassium, rubidium, and cæsium); in Group 2 (glucinum, magnesium, calcium, strontium, and barium), though here we have inversions of the rule in the relative abundance of magnesium and calcium, and of strontium and barium. It is also seen in the third group (boron, aluminum, scandium, gallium, etc.); in the fourth group (carbon, silicon, titanium, zirconium, and cerium); in the fifth (nitrogen, phosphorus, arsenic, and antimony); in the sixth (oxygen, sulphur, selenium, and tellurium), here again there being an inversion as regards the first and second; and in the seventh (fluorine, chlorine, bromine, and iodine). It is also seen in Group 8, in the case of iron, nickel, and cobalt, according to their atomic weights, though the atomic numbers of nickel and cobalt are reversed in order. As Clarke says: " We are dealing with an evident tendency of which the meaning is yet to be discovered. That the abundance and associations of the elements are connected with their position in the periodic system seems, however, to be clear. The coincidences are many, the exceptions are comparatively few."

The relation of the abundance of the elements to the periodic law has also been discussed recently by Harkins,[16] who holds that the abundance of the elements is " related to the atomic number and not to the periodic system," that the abundant elements are those of low atomic weight with an atomic number less than 29, and that the elements with even-numbered atomic numbers surpass in abundance the odd-numbered. It would take us too far from our proper subject to discuss this very interesting topic here, but we may examine briefly a hitherto unrecognized phase

[15] Clarke, F. W.: " Data of Geochemistry," *U. S. Geol. Surv. Bull.* 695, p. 39, 1920.

[16] Harkins, W. D.: *Jour. Amer. Chem. Soc.*, xxxix, p. 856, 1917.

TABLE III.

Periodic Classification of the Elements.

	Group 0	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
1		H 1							
2	He 4	Li 7	Gl 9.1	B 11	C 12	N 14	O 16	F 19	
3	Ne 20	Na 23	Mg 24.4	Al 27.1	Si 28.3	P 31	S 32	Cl 35.5	
4	A 39.9	K 39.1	Ca 40.1	Sc 44.1	Ti 48.1	V 51	Cr 52.1	Mn 55	Fe 55.9 Co 59 Ni 58.7
5	…	Cu 63.6	Zn 65.4	Ga 70	Ge 72.5	As 75	Se 79.2	Br 79.9	
6	Kr 82.9	Rb 85.5	Sr 87.6	Yt 88.7	Zr 90.6	Cb 93.5	Mo 96	…	Ru 101.7 Rh 103 Pd 106.5
7	…	Ag 107.9	Cd 112.4	In 115	Sn 118.7	Sb 120.2	Te 127.5	I 126.9	
8	Xe 130.2	Cs 132.9	Ba 137.4	La 138.9	Ce 140.3	…	…	…	…
9	…	…	…	Rare Earth Metals.	…	…			
10	…	…	…	…	…	Ta 181	W 184	…	Os 191 Ir 193.1 Pt 195.2
11	…	Au 197.2	Hg 200.6	Tl 204	Pb 207.2	Bi 208	…	…	
12	…	…	Ra 226	…	Th 232.5	…	U 238.2	…	

of the relation of the occurrence of the elements to their position in the periodic table, shown by the study of minerals and of igneous rocks, and taking into consideration the chemical relations of the various elements.

THE PETROGENIC AND METALLOGENIC ELEMENTS.

In Table III is presented the periodic classification of the elements, as usually given.[17] The atomic weights are stated in round numbers, most of the elements of the " rare earths " are omitted, as their relative positions are still in dispute, as are also the radio-active elements, except radium.

Here, as has been commonly recognized, the most abundant elements in the earth's crust, being of generally low atomic weight (or atomic number), occupy the upper part of the scheme, forming the series 1 to 4 of Groups 1 to 8. These, with some others in series 6 and 8 to be mentioned presently, may be called the " Rock Elements," as they are the essential elements, in greater or less amount, of the igneous rocks of the earth's crust, of which they constitute at least 99.9 per cent. by weight.

In the lower part of the scheme are elements of higher atomic weight which, with others, in series 5 and 7, to be mentioned later, are but seldom, if ever, found in determinable quantities in igneous rocks, but which occur chiefly as ores, or as native metals. These may therefore be called the " Ore Elements." There would seem to be a very definite and distinctive difference between these two groups as regards their general chemical relations—a difference that has apparently not heretofore been observed.

Intermediate between the upper and lower part of the scheme is a zone, series 5 to 8, including elements that our study of minerals and rocks shows to belong partly to the rock elements, and partly to the ore elements. It is found that their relations to the one or the other is clearly distinguished by tracing a meander that separates them into alternate or interlocking vertical columns, the spaces thus made opening above into the division of the rock elements and below into that of the ore elements. Thus, as we shall see, Rb and Cs, Sr and Ba, Yt and La, Zr and Ce, Cb?, and Mo are to be considered as rock elements; while Cu and Ag, Zn and Cd, Ga and In, Ge and Sn, As and Sb, S, Se, and Te, and

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[17] This table is based on that given by Clarke, *U. S. Geol. Survey Bull.* 695, p. 37.

Br and I, are ore elements. These differences are indicated by some of their general chemical relations and by the facts of their occurrence as minerals, that is, as components of the earth's crust.

Flanking the main part of the table is Group 0, the column of the inert gases, from helium to xenon. At the bottom are the radio-active elements, chiefly radium, thorium, and uranium, with others (some more or less hypothetical) that have been recently discovered. On the right is the column of Group 8, that of the triads. Of these, iron, cobalt, and nickel, are to be considered as rock elements, and the two triads of the platinum metals as ore elements.

It may be as well to suggest here, and to use henceforward, two terms as a matter of convenience. We may call the " rock elements " *petrogenic* and the " ore elements " *metallogenic*. These terms are not only short and self-explanatory but, having an adjectival form, are convenient for use. The distinctive chemical differences between the petrogenic and the metallogenic groups of elements, as regards their *occurrence in the earth's crust,* will be now set forth; and, it may be said, that these differences seem to divide them into two " natural " groups, which may be of significance in a study of the constitution of the earth. In the present paper it is best not to go very deeply into technical mineralogical details, and only the main facts will be stated, leaving the details for presentation elsewhere.

The petrogenic elements occur normally in nature as primary minerals, forming oxides, silicates, fluorides, and chlorides; but never, or only exceptionally, as sulphides, selenides, tellurides, arsenides, antimonides, bromides, or iodides. With the exceptions of iron and nickel, they are never found in the form of native metals. The metallogenic elements, on the other hand, normally (as primary minerals), form sulphides, selenides, tellurides, arsenides, antimonides, bromides, or iodides, but only seldom and exceptionally do these occur as (primary) silicates, oxides, fluorides, or chlorides. They are frequently met with as the " native " elements. There are, it is true, some exceptions to these statements (as with iron, which forms three common sulphides, and with tin which occurs mostly as the oxide); but taken broadly, and as applying to the two several groups as a whole, the distinction seems to be valid.

The oxides of many of the electropositive petrogenic ele-

ments are known to occur as minerals; those, that is, that are stable and are not readily soluble. They include periclase (MgO), corundum (Al_2O_3), quartz and tridymite (SiO_2), rutile (TiO_2), ilmenite (($Fe,Ti)_2O_3$), chromite ($FeO.Cr_2O_3$), pyrolusite (MnO_2) and other oxides of manganese, hematite (Fe_2O_3), and magnetite (Fe_3O_4). All of the electropositive petrogenic elements form silicates, and, indeed, they form the overwhelming majority, certainly 99.9 per cent. of all known silicates by weight. Besides the simple silicates are borosilicates, fluosilicates, titano-silicates, and zirconosilicates, all of them salts of petrogenic elements. A few sulphosilicates are known, but they are very rare, and there are no known arseno-, antimono-, seleno- or tellurosilicates.

Fluorides and chlorides of sodium, potassium, ammonium, magnesium, calcium, aluminum, cerium, iron, and manganese, are known as minerals, and some of them are quite common, as NaCl, KCl, and CaF_2. On the other hand, neither bromides nor iodides of these elements occur as minerals, though there is an exces-sively rare calcium iodate. Fluorine replaces hydroxyl in several silicates, as in topaz and chondrodite, and it is also present in small amounts in hornblendes and micas, while chlorine is present in small amount in some silicate minerals, as those of the sodalite and scapolite groups. Until we reach vanadium, with atomic weight 51 and atomic number 25, no sulphides occur as minerals, except calcium sulphide, which occurs as a rare mineral (oldham-ite) but only in a few meteorites. A very rare vanadium sulphide, found only in one locality, an extremely rare chromium-iron sulphide, occurring only in a few meteorites, and a rare terres-trial manganese sulphide are known. No arsenides, selenides, or tellurides of these elements, or of those preceding them in atomic number, are known. With the iron group, we find sulphides very common, the sulphides of iron, pyrite, marcasite, and pyrrhotite, being common minerals, and sulphides of nickel and of iron and nickel, as well as their arsenides, are widespread ore minerals. Sulphides and arsenides of cobalt are also fairly common. The sulphide of molybdenum is the only usual mineral of this element, though a few other minerals containing it (as secondary molyb-dates) occur. Selenides, tellurides, and antimonides of iron are apparently unknown in nature, though of nickel there are some very rare minerals of this character. It will be seen that such

compounds (sulphides, arsenides, etc.) of the petrogenic elements are all of those of rather high atomic weight and in the groups of highest valence, especially common in the triad group iron-cobalt-nickel.

Turning to the metallogenic elements, we find that many of them exist in nature uncombined, notably copper, silver, gold, mercury, arsenic, antimony, bismuth, sulphur, selenium, tellurium, and the metals of the platinum group. Native zinc, lead, tin and tantalum are also reported, but in some cases doubtfully.

As minerals the oxides of these elements either do not exist (as of gold, mercury, and the platinum metals), are of extreme rarity, or are certainly or almost certainly of secondary origin, as those of copper, zinc, arsenic, and antimony. Tin oxide, the common ore of this metal (cassiterite), is an apparent exception, but it would seem to be possible that, in some cases at least, it is of secondary origin, a sulphide being the primary compound.

Primary silicates of the metallogenic metals are very rare. There are none of gold, silver, mercury, thallium, tantalum, tungsten, or the platinum metals. Silicates of copper and zinc are quite common, but are in all cases almost undoubtedly of secondary origin. There are, however, silicates (possibly primary) of tin, lead, and bismuth, but they are mineral rarities, and many mineralogical museums and collections have no specimens of them.

No fluorides of any of the metallogenic elements are known as minerals, but insoluble chlorides and oxychlorides of copper, silver, mercury, and lead are known, though rare. On the other hand, as native bromides and iodides we know only those of copper, silver, mercury, and lead—all metallogenic elements.

The typical, and by far the most abundant, native compounds of all these metallogenic elements then are the sulphides, arsenides, antimonides, selenides, and tellurides, with the complex sulphosalts. These form the main, and in some cases the only, sources of most of the metals. Indeed, of gold, mercury (except the common sulphide, a chloride, and two doubtful iodides), and thallium (except a rare sulphide), the only native compounds known are selenides and tellurides; and conversely, the only native selenides and tellurides known are of copper (rare), silver, gold, mercury, thallium, lead, and bismuth, except that there is a very rare nickel telluride. Oddly enough the only native compounds known of

the platinum metals are ruthenium sulphide and platinum arsenide, no selenides or tellurides of these being known.

Returning to the intermediate interlocking meander zone, it may be well to point out some features that show to which of the two main groups the several elements there belong, and allude to another feature of interest regarding this part of the table.

Rubidium and cæsium are only known as silicates, cæsium forming the rare polysilicate pollucite, and both entering in small amount into other silicates, as beryl, lepidolite, and a few others. Strontium and barium, apart from their sulphates and carbonates of secondary origin, enter only into silicates, a barium silicate forming a member of the feldspar group, and both being the bases in some of the hydrous zeolites. The proper position of yttrium and lanthanum, in Group 3, is somewhat uncertain, but they both enter into the composition of various silicate minerals, and are not known as sulphides, arsenides, etc. The position of zirconium and cerium is quite clear; both form silicates, zircon being especially widespread among granitic rocks, and they also enter into the composition of some members of the pyroxene group. The position of columbium (niobium) is also somewhat uncertain, as no silicates of it are known; but it is the base in some titanates, and its general affinities as to mineral occurrence would place it almost surely with the petrogenic elements. Closely related to it, and occurring with it almost always, is tantalum, whose true place is uncertain. Both these elements, however, are very rarely met with. The researches of Hillebrand [18] have shown that molybdenum is very widely distributed among the more silicic igneous rocks, such as granites, so that, even though its most abundant mineral is the sulphide, it should be reckoned with the petrogenic elements.

Of the intermediate metallogenic elements, the positions of copper and silver are unquestionable, as both occur combined most frequently as sulphides, and other such minerals. Silver does not occur as a silicate or oxide; but silicates and oxides of copper are not uncommon, though these are of secondary origin. The same may be said of zinc and cadmium, the oxide and silicate of zinc being secondary. Gallium and indium are found only in zinc sulphide (sphalerite), and germanium occurs only as a sulphide with silver and tin. Though tin is most commonly met with as the oxide (as

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[18] Hillebrand, W. F.: *Amer. Jour. Sci.*, vi, p. 209, 1898.

well as a rare silicate), yet sulphides of it are known, so that, in spite of its frequent occurrence as oxide, it is to be reckoned with the metallogenic elements. Arsenic and antimony, as well as selenium and tellurium, belong, of course, in this group; as does sulphur, the necessary inclusion of which among the metallogenic elements carries them somewhat into petrogenic territory, and renders the meander somewhat unsymmetrical toward this end. Bromine and iodine, as we have seen, are only met with in nature in combination with metallogenic elements, so that they may probably be placed with these. The metals of the ruthenium and the platinum groups clearly belong here, because of their occurrence as metals, and because of the existence of the sulphide of ruthenium and the arsenide of platinum as the only native compounds known.

On referring to the periodic classification presented in Table III, it will be seen that the intermediate, meandered zone, where the petrogenic and the metallogenic elements interlock, shows a very large proportion of elements with atomic weights that are quite far removed from whole numbers, which would imply, as has been suggested by Harkins, that this is especially the region of isotopes. Whether this is fortuitous, or whether it is (if it be true) connected with the division here suggested of the elements into the petrogenic and the metallogenic groups, is quite unknown, and it is needless here to speculate upon the subject.

It should be mentioned that the relations between the positive and the negative elements, and their occurrence in nature as minerals, as set forth above, form an elaboration and an extension of what Clarke has already called attention to,[19] namely: " In combination unlike elements seek each other, and yet there appears to be a preference for neighbors rather than for substances that are more remote. . . . The elements of high atomic weight appear to seek one another, a tendency which is indicated in many directions, even though it cannot be stated in the form of a precise law. The general rule is evident, but its significance is not so clear." A possible significance, or rather a possible connection between this rule and the occurrence of the elements, both as to their relative abundance and their mutual relations, in the earth's crust and below it, may be suggested here, as a somewhat speculative hypothesis.

[19] Clarke, F. W.: " The Data of Geochemistry," U. S. Geol. Survey, Bull. 330, p. 35, 1908; and Bull. 695, p. 39, 1920.

THE INTERIOR OF THE EARTH.

The hypothesis (already adverted to), that the interior of the earth is composed, at least in part, of an iron-nickel alloy like that which composes many meteorites, is commonly held. This is based on the mean density of the earth, its rigidity and magnetic character, and the composition of many meteorites, the siderolites, which may be regarded as fragments of a preëxisting large body. Following Charles Darwin and Durocher, who published their views in the first half of the last century, the idea is now held by many that the material composing the interior of the earth is arranged, in a general way, according to relative density,[20] there being a nucleus or core of iron-nickel and possibly other heavy metals, above this a zone of heavy silicate rocks, and at the surface the lighter silicate rocks of the " crust," but presumably passing gradually one into the other, without sharp borders.

Wiechert and Knott have recently shown, through a study of the propagation of earthquake waves, that there is a change in the material, or in the physical properties of the material, at a depth of about 0.5 of the earth's radius. Still more recently, by laboratory measurements of the compressibility of rocks, as well as by the study of earthquake waves, Adams and Williamson,[21] of the Carnegie Geophysical Laboratory, have shown that the much greater density of the interior of the earth cannot be accounted for by the compressibility of the materials, whether rocks or metals. They are also led to the conclusion that, while there is segregation of heavier material toward the centre, that the change is continuous, and not discontinuous, as is held by Wiechert and Knott.

Following the views of Adams and Williamson, and accepting a lower zone of nickel-iron beneath the silicate " crust," I would suggest here the idea that the central core, the real nucleus, of the earth is composed of the metallogenic elements, that is, the elements or metals of highest atomic weight, either as " native " metals, or possibly in the form of selenides, tellurides, arsenides, antimonides, bromides, and iodides. Above this would be the nickel-iron zone, and above this the silicate crust.

[20] See, for example, Suess, " The Face of the Earth " (English translation), Vol. iv, p. 547, 1909; Daly, " Igneous Rocks and Their Origin," pp. 162–168, 1914.

[21] I must express my thanks to my colleagues for permission to mention briefly here some of their conclusions, which have not yet been published.

We cannot here discuss this suggestion in all its rather complex aspects. But the somewhat intermediate chemical character of the metals of the iron group, with manganese and chromium, is in accord with the hypothesis, differing as they do from the other petrogenic elements in their occurrence as sulphides and arsenides, in which they resemble the heavier metallogenic elements. Iron is the fourth most abundant element, and if the position of the nickel-iron zone, or a zone of mixed alloy with silicate rocks, were comparatively near the surface, this would be expected. The occurrence of iron-bearing basalts at the surface (met with in Greenland, Russia, Spain, and elsewhere) is also in line with this supposition.

Again, as on this supposition the true metallogenic elements are most deeply buried, their relative scarcity at the surface is readily understandable. Forming the nuclear core, not only would their total volume be relatively small, but it would also be difficult for them to find their way, even as vaporized or soluble compounds, from the great depths to the surface. The generally low melting-points of the ore minerals is also in line with the opinion of Adams and Williamson that the deepest interior is not entirely a rigid solid, but more in the nature of a very viscous, thick liquid, which damps the transverse earthquake vibrations. The possible factor of the disintegration of the elements of highest atomic weight must be taken into account, but more cannot be said here on this topic.

It is of interest to note that this idea, that the elements of higher atomic weights, the metallogenic elements, occupy for the most part the deepest portions of the earth's interior, is in harmony with Abbot's view as to the distribution of the elements in the sun.[22] He points out that the elements showing the most intense spectrum lines are those of low atomic weight, with the exception of the negative elements, none of which (with the possible exception of oxygen), for some unknown reason, show solar spectral lines. It is interesting to compare Abbot's table of intensities (page 91) with the elements as presented in our Table III of the periodic arrangement. It will be seen that the first 22 elements showing the most intense lines are all terrestrially petrogenic elements, and that (apart from the negative elements) all the terrestrial petrogenic elements are among those that show

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[22] Abbot, C. G.: "The Sun," 1911, pp. 91, 94, 99, 104, and 252 ff.

the more intense lines, with the curious exceptions of glucinum, cerium, and especially potassium, which show but very weak lines. The order is not the same, but the first ten elements in order of spectral intensity include calcium, iron, hydrogen, sodium, magnesium, silicon, aluminum, and titanium, which, with oxygen, potassium, and phosphorus, are the first eleven elements in order of abundance in the earth's crust. On the other hand, the metallogenic elements show the least intense or no solar spectrum lines. Thus in Abbot's intensity tables Nos. 23 to 36 (the last) include in order palladium, copper, zinc, cadmium, germanium, rhodium, silver, tin, and lead. The metals of the platinum group, with tungsten, bismuth, mercury, thallium, and one or two others, give extremely feeble or doubtful lines. As Abbot shows, taking the elements in groups of order of intensity, this diminishes with increase in the mean atomic weight of the group.

Abbot explains this distribution, to which the only real exceptions are cerium, glucinum, and potassium, by the supposition that " the explanation of the decrease of intensities with increasing atomic weights seems to depend on the depth of these gases below the sun's surface," and this supposition is confirmed by the spectrum observations of displacements of the lines of various elements due to pressure and those that show in the " flash " spectra during eclipses. The coincidence between the occurrence of the elements in the earth and in the sun, as regards relative abundance and depth, is apparently so very close and detailed as to be suggestive of a similar arrangement in both bodies. It is also quite in harmony with the general idea of arrangement according to specific gravity or " gravitative adjustment."

We may conclude therefore that the metallogenic elements are rare on the earth's surface and do not show intense spectrum lines in the sun, because they are too deeply buried in both. Connected with this, however, is the difference in the chemical relations already pointed out, the significance of which is as yet problematical.

It might be pointed out here that such a theory of the vertical distribution of the elements seems to be opposed to Chamberlin's hypothesis of the planetesimal origin of the earth, though the matter cannot be discussed in this paper. Attention may only be called to the fact, probably very significant in this connection, that the melting points of the oxides and silicates, the typical natural

compounds of the petrogenic elements, are much higher than those of the sulphides and arsenides, the typical natural compounds of the metallogenic elements. The bearing of this will be discussed elsewhere.

Much more might be said of this suggestion of the distribution of the elements of highest atomic weight and greatest density at the centre. The idea is not wholly new, having been held speculatively by others. One might even recall, to pass from science to fiction, that the idea was, in a way, foreshadowed by Jules Verne, who in one of his stories describes a comet or huge meteorite composed of telluride of gold.

CORRELATION OF THE ELEMENTS.

But we have wandered far from our proper topic, the crust of the earth, having reached not only the centre of the earth, but the sun, and become enmeshed in somewhat transcendental chemical speculation. Let us come back to the surface of the earth.

Before returning, however, to the consideration of the actual crust and its rocks, it may be as well to examine briefly a feature of the mutual relations of the elements (for the most part petrogenic), that is shown us by chemical study of the rocks and of the many minerals with which we are acquainted. Since the chemical analysis of rocks and minerals began to assume large proportions, so that sufficient and sufficiently accurate data became available, it has been noticed that certain elements are prone to be found in rocks of certain general compositions, and also in association with one another in minerals. In other words, there has been observed a certain correlated distribution of the elements in the earth's crust, that is, in the rocks and minerals composing it, by which certain of the elements tend to occur together in greatest abundance or most often, while other elements are seldom if ever found along with these. As this is a matter of considerable interest and importance from the mining engineer's point of view, several attempts have been made to formulate the relations, and it will be pertinent to give a very brief account of the subject.

Among the earliest of the more modern workers to investigate this problem are Vogt, Kemp, and De Launay,[23] who confined

[23] Vogt, J. H. L.: *Zeits. Prakt. Geol.*, 1898, p. 326; Kemp, J. F.: " Ore Deposits," 3d edition, pp. 34–37, 1900; De Launay, L.: " La Science

their attention chiefly to whether the various elements considered were most abundant in the more or the less siliceous rocks.

The writer pointed out [24] that "the relations are more complex and are dependent, not so much on the relative amount of silica, as on the relative amounts of other constituents, notably soda, potash, iron, magnesia, or lime." Such relations of common association are shown, in part among the most abundant constituents of rocks and minerals, and in part among the rarer ones, generally in connection with the more abundant. For the most part, the relations so far observed, which may be considered as best established, are confined to the petrogenic elements, as would be expected, but there seem to be similar relations, not yet quite clear, between some of the metallogenic and the petrogenic elements.

Broadly speaking, silica, alumina, soda, and potash tend to go together; thus the rocks that are highest in silica have, in nearly all cases, alumina and the alkali metals as the next most abundant constituents. At the same time, the alkali metals, and lime (not iron or magnesia), tend to go with alumina; so that a very large number, and among these the most common, of the silicate minerals are silicates of alumina and (or aluminosilicates of) soda, potash, and lime. The iron oxides and magnesia do not show nearly so strong a tendency to combine with silica or with alumina. In this connection may be mentioned a tendency toward combination with (or affinity for) silica, which may be expressed thus:

$$K_2O > Na_2O > CaO > MgO > FeO.$$

That is, potash will endeavor to take all the silica that it can, so far as is compatible with certain physical conditions, soda next, and so on; iron being the only very abundant element (except silicon) that commonly forms an oxide alone, that is to say, uncombined with silica. This general law or rule, which is based on the most generally observed relations among rock-forming minerals, is the basis of a recently introduced classification of igneous rocks, and it

Géologique," p. 637, 1906. Cf. also Hillebrand, W. F.: *U. S. Geol. Survey,* *Bull.* 700, p. 25, 1919; and Clarke, F. W.: *U. S. Geol. Survey, Bull.* 695, p. 13, 1920.

[24] Washington, H. S.: *Trans. Amer. Inst. Min. Eng.,* p. 751, 1908; Cf. Washington, "Manual of the Chemical Analysis of Rocks," 1st edition, p. 14, 1904; 3d edition, p. 17, 1919.

gives promise of fruitful application in the future. A similar "order of affinity" as regards alumina is also true of the same elements.

Magnesia and the iron oxides tend to go together, or to replace each other in many minerals, which seems to be of much the same import, and these oxides are, as we have seen, generally opposed to soda, potash, and lime.

Among the more interesting of such correlations are those of soda and iron on the one hand, and of potash and magnesia

FIG. 1.
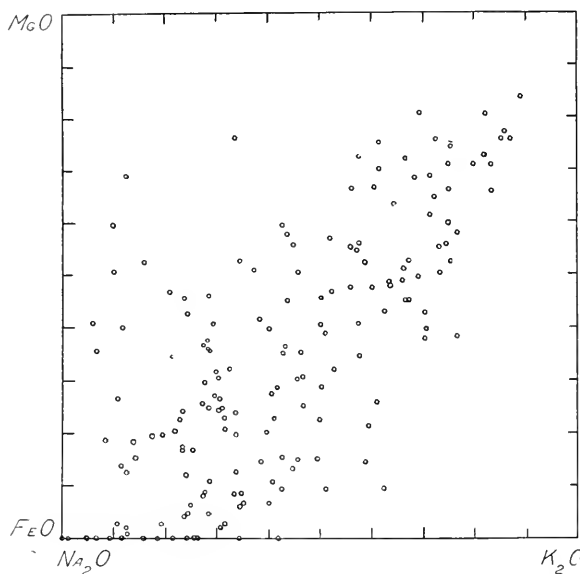
Relation of Na and Fe to K and Mg.

on the other, these two pairs tending to go together. This is shown by many minerals, the details concerning which it is unnecessary to give here, though there may be mentioned the sodic pyroxenes, which contain much iron and little if any magnesia, and the potassic micas, which generally contain more magnesia than iron along with the potash. Study of many analyses of igneous rocks also brings this relation out very clearly, and it is expressed in the above figure (Fig. 1) published some years ago.[25] In this the abscissas represent the relative amounts

[25] Washington, H. S.: *Proc. Natl. Acad. Sci.*, i, p. 574, 1915.

of soda and potash, and the ordinates those of iron oxide and magnesia. The general drift of high soda coincident with high iron, and conversely of high potash with high magnesia (though such rocks are comparatively few), is clearly shown, and, as the data are derived from numerous analyses, and are substantiated by many others more recently made, the general " drift " may be considered as fairly well established. That the points fall in a rather broad zone, instead of along a narrow line, is to be attributed to the complications that may be introduced in such correlations by the presence of silica, lime, and possibly aluminum or titanium.

It may be mentioned here, *en passant*, that, curiously enough, the same correlation between these two pairs of elements, soda and iron, and potassium and magnesium, seems to hold good in the organic world.[26] This is apparently shown by the following facts : In autotrophic plant metabolism potash is an essential element, as is also magnesium, in that chlorophyll (which in the leaves acts as the carbon-transferring substance) is a magnesium salt of a complex organic acid, while sodium and iron are generally toxic toward (at least the higher, gymnospermous and angiospermous) plants. On the other hand, sodium, rather than potassium, is the alkali metal essential to the higher animals, salt being a very necessary article of diet (in part because of its chlorine, and in part because of its sodium, content), and sodium is present in the blood plasma; and at the same time, hæmoglobin and its derivatives (which act as oxygen carriers, and are analogous to chlorophyll in plants) are iron salts of organic acids closely related to that of chlorophyll; while, similarly potassium and magnesium are more toxic toward the higher animals than are the other pair.

Let us now pass briefly in review some of the correlations that are shown in igneous rocks by the rarer, and generally petrogenic, elements with the most abundant ones. In the first place, the rocks that are dominantly sodic seem to show the greatest tendency towards the segregation of many of the rarer elements. Thus, lithium, zirconium, cerium (and some of the other rare earth metals), chlorine and fluorine, and probably glucinum and tin, are found most often, both as components of minerals, and in rocks, that are high in soda. Barium seems to be most abundant

[26] Washington, H. S.: *Proc. Natl. Acad. Sci.,* ii, p. 623, 1918.

in those that are high in potash; titanium,[27] manganese, vanadium, nickel, and cobalt, in those that are specially high in iron; and chromium and platinum in those that are high in magnesium. Of the proclivities of the more truly metallogenic elements, as gold, silver, mercury, lead, and zinc, we know little as yet, but further study may indicate such relations, if they exist.

It is needless to enlarge here on the bearing of such observations on the practical search for ores and metals, especially those of the rarer kinds, some of which are now coming into prominence, such as tungsten and tantalum for electric lights, and zirconium for refractories. It will be self-evident that a knowledge of the rocks of a region can thus give us a clue as to what elements, or their ores, may be most likely met with, so that, for instance, we would not search for platinum in a region of sodic rocks, but would here rather look for the minerals of cerium, the rare earths, uranium, or tungsten.

COMAGMATIC REGIONS.

Let us now return to the earth's crust and endeavor to answer the second question propounded above, namely, whether all large portions of the crust are alike in general, or whether they show marked differences; that is, whether the crust is essentially alike or unlike over different areas.

Nearly fifty years ago Vogelsang[28] pointed out that the igneous rocks of certain districts showed certain textural or mineral characters in common, which served to distinguished them from the rocks of other districts. The same idea was expressed later by Judd,[29] and still later by Iddings,[30] the latter showing that the differences between different districts were referable ultimately to differences in the chemical composition of the rocks. Such districts were called "geognostische Bezirke" by Vogelsgang, "petrographic provinces" by Judd, the latter name being that in common use, Iddings using the term "consanguinity," while the writer later[31] called them "comagmatic regions," to indicate the

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[27] Titanium also evinces preference for sodium, like its congener zirconium.

[28] Vogelsang, H.: *Zeits. deutsch. geol. Ges.*, xxiv, p. 525, 1872.

[29] Judd, J. W.: *Quart. Jour. Geol. Soc.*, xlii, p. 54, 1886.

[30] Iddings, J. P.: *Bull. Phil. Soc. Wash.*, xii, p. 128, 1892.

[31] Washington, H. S.: *Carnegie Inst. Publ.*, No. 57, p. 5, 1906.

idea that the various rocks of a given region are derived from a common magma, by processes of so-called differentiation. Into the discussion of differentiation we cannot even begin to enter here, though it forms one of the most important and most complex features of petrology, the science of rocks.

The proper study of petrographic provinces, or, as we shall here term them, comagmatic regions, is as yet, so to speak, in its infancy. Only a few regions have been described at all adequately from the most general point of view, such as the Christiania region in southern Norway, that of Central Montana, the Yellowstone Park, and the volcanoes of western Italy; and these descriptions leave much to be desired.

Indeed, even the fundamental data for our definition of a comagmatic region are somewhat uncertain and the application of the idea is somewhat loose. Thus, considering the time element, the life of a region may extend over many geological periods, as that of Great Britain from the Silurian to the Tertiary; or it may be confined to but little more than one period, as with the western Italian volcanoes. The areal extent may vary from many thousands of square miles to a few hundreds, though we are beginning to believe that the smaller " regions " are probably to be regarded as but parts of larger ones. The shape of the area may also vary; it may be more or less equilateral, a long zone, either broad or narrow and perhaps forked, or be evident only as small, separate, and apparently structurally unconnected occurrences of similar rocks.

Although some of the characters of any given region may be most evidently recognizable by the mineral features, such as the color of the pyroxenes or the peculiarities of the feldspars, yet these are all dependent on the prominent chemical characters of the magma, so that the chemical characters constitute the fundamental basis of distinction and characterization. In order to show the reader how, and in how far, the chemical characters of various portions of the earth's crust may differ, it will be well to note very briefly some of the best-known comagmatic regions of the earth, stating only their most prominent chemical features and omitting all details.

In the United States we find a long zone of disconnected areas whose rocks are dominantly sodic. This zone apparently begins in southwest Greenland, appears as a group of very similar small

areas in Ontario, Quebec, and New England (the so-called Novan-
glian region), appears in New Jersey, Virginia, probably North
Carolina, in Arkansas, and finally as several areas in Texas. It is
apparently continued south into Tamaulipas in Mexico; and what
may be a continuation of it appears in some of the Antilles, in
Brazil, and as far south as Paraguay. These areas in the United
States are marked solid black in Fig. 2. The large " Canadian
shield " around Hudson's Bay forms another region, which is
dominantly calcic (anorthosites), marked with v's on the map.
Along the Appalachian uplift, and probably extending into

FIG. 2.
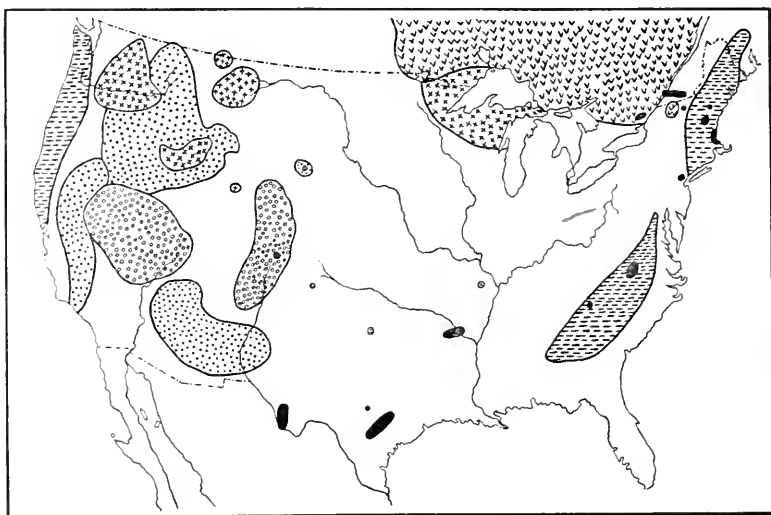
Comagmatic Regions of the United States.

Maine, is another region, the rocks of which are characteristically
rather sodic granites, though some very unusual rocks occur along
this zone. This is marked with dashes (—) on the map. The
sodic areas just mentioned may be connected with this. West of
the Appalachians we find a few, small sporadic occurrences of
peculiar rocks, high in potash and magnesia, as in New York,
Pennsylvania, Kentucky, and Arkansas, which seem to be distinct
from the preceding, and which may represent the great body of
magma that underlies this part of the Mississippi Valley.

Around Lake Superior, in Minnesota, Wisconsin, and Michi-
gan, and probably extending into Canada to the north, is an area

of igneous rocks that are low in silica but high in lime and iron oxides. To the last feature is due the importance of this region for its very abundant iron ores. It is marked with x's on the map. In the southern part of the Mississippi Valley, about the Ozark uplift, are some small and as yet little-studied occurrences of granitic rocks, which seem to form a distinct region.

West of the Mississippi Valley the comagmatic relations are more complex, as are the geological structures, but we can distinguish some fairly well-defined comagmatic regions. One of the most clearly marked is that which extends from, and possibly beyond, the Canadian border through central Montana, where it is represented by several volcanic centres described by Pirsson and others, into Wyoming, and with patches that probably represent it in eastern Colorado. These rocks are characterized by decidedly high alkalies, and with potash generally dominating soda. The areas are marked by x's on the map. Covering the great plateau of Colorado, Utah, and Nevada, with parts of Idaho and Wyoming (including the Yellowstone Park), and probably in northern New Mexico and Arizona, is a large and complex region, the rocks of which are decidedly of average composition, distinctly high in silica, moderate lime and alkalies, and low iron and magnesia. North, west, and south of this is a rather ill-defined region, whose rocks are similar but somewhat more calcic. The first is distinguished by small circles and the latter by dots on the map. These regions need further study, and it is doubtful if they should be treated separately.

In southern Idaho and in Washington and Oregon are the very extensive flow basalts of the Snake and Columbia Rivers, high in lime and iron oxides, which resemble chemically the rocks of the Lake Superior region and which are marked similarly on the map. The true relationship of these to the surrounding regions is doubtful. Along the Pacific Coast, chiefly in California, but extending to the north about as far as Puget Sound, there are indications of a narrow zone of decidedly sodic but rather highly silicic rocks. This may extend south along the west coast of Mexico, and may there be connected with the origin of the jadeite objects found in that country, the exact provenance of which is unknown. Thus may petrology aid archæology.

The long chain of the Andean volcanoes seems to form a continuation of the main Cordilleran region, which is continued

northward along the Aleutian volcanoes, and thence southward, along the west coast of the Pacific, through the volcanoes of Kamchatka, Japan, and the Philippines, and so on to the Dutch East Indies. This so-called " Circle of Fire" surrounds a large area, that of the Pacific Islands, whose rocks are dominantly basaltic, that is, low in silica and alkalies, and high in lime, magnesia, and iron, associated here and there with occurrences of alkalic rocks.

In Europe the various comagmatic regions are so numerous, so complex, and so little known from this point of view, that only a few need be mentioned. There is the extensive, though broken-up, region that embraces the British Islands and their outliers, with Iceland, Eastern Greenland, Jan Mayen, Spitzbergen and Nova Zembla, the rocks of which are dominantly basaltic. The highly sodic Christiania region in southern Norway has been well studied by Brögger, as has the calcic Bergen region by Vogt. Germany and Austria are filled with a complex of different regions, the relations of which are not yet clear, but which seem to be either dominantly sodic, as that of Bohemia, or with basaltic tendencies. The Alps and the Tyrol form a central region of prevailingly granitic rocks which differ markedly from the various and different regions that surround them; this is a point to which we shall recur. In Italy is the so-called Roman comagmatic region, embracing the volcanoes along the west coast from Bolsena to Vesuvius, the rocks of which are decidedly unusual in their very high potash, with considerable lime. A zone of distinctly sodic rocks appears to extend from southern France and eastern Spain, down Corsica and Sardinia, through the island of Pantelleria, into Tripoli. Hence, by way of Kordofan, this region is possibly connected with the highly sodic one that stretches from Abyssinia down the Ethiopian Rift Valley in East Africa, and which branches northwardly along the Red Sea and Arabia as far as Syria. At the east end of the Mediterranean, on the other hand, is a region embracing Greece and the Balkan Peninsula, the Archipelago, and western Asia Minor, whose rocks resemble very closely those of the Colorado plateau and of the Andes volcanoes.

We could go on thus over the surface of the earth, so far as its rocks are sufficiently well known chemically. Unfortunately, this is not the case with many large, and otherwise thoroughly studied, areas or regions, such as, for instance, the Greater An-

tilles, Cuba, Jamaica, Haiti, and Porto Rico. But this very rapid sketch will serve to give the reader some idea of how diversified, chemically, are the different portions of the earth's surface.

It has been suggested by several prominent petrologists [32] that the comagmatic regions may be referred genetically to two large types of magma or " provinces," called " alkaline " and " subalkaline " by Iddings, or " Atlantic " and " Pacific " by Becke. The latter goes so far as to attempt to ascribe all the comagmatic regions to two areas, the one dominantly alkalic and surrounding the Atlantic Ocean, and the other more calcic and surrounding the Pacific. Harker, furthermore, would connect these two main types of comagmatic region with two main types of crustal movement or stress, such as are recognized by Suess, which give rise to different types of coast, mountain formation, etc. In the opinion of the writer such recognition of but two types is not consonant with what we know of the general distribution of the igneous rocks. The whole subject is very complex, far too much so for proper discussion here, and the data available seem to the writer to be inadequate for very broad generalizations at present.

CHEMICAL COMPOSITION AND ROCK DENSITIES.

The above outline of comagmatic regions leads us to the consideration of two subjects with which we may close this sketch of the chemistry of the earth's crust; that is, the relation between the chemical composition of rocks and their density, and that between these and the theory of isostasy.

In the preceding pages we have considered igneous rocks almost only from the chemical point of view. As we know, however, they are actually aggregates of definite chemical compounds, minerals, mostly silicates. Furthermore, we know that magmas of the same general chemical composition may crystallize as diverse aggregates of different minerals, according to the conditions that obtain during solidification. If we know the chemical compositions of the various rock-forming minerals, the quantitative mineral composition may be readily calculated from the chemical analysis of the rock. But from what has just been said, it is evident that the particular mineral aggregate to be

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[32] For some general discussion of this and related topics, the reader is referred to: Harker, " The Natural History of Igneous Rocks "; Iddings, " Igneous Rocks," Vol. i; and Daly, " Igneous Rocks and Their Origin."

calculated will depend on the conditions controlling solidification. It is also obvious that, if we know the mineral composition and the densities (specific gravities) of the minerals, that of the rock as a whole may be readily calculated.

In the conception and elaboration of a system of classification of igneous rocks that was proposed some years ago by some American petrologists, the chemical composition of igneous rocks was regarded as their most fundamental character, and therefore that on which their classification was primarily based. But, in order to recognize the fact that they are actually mineral aggregates and so as to be able to compare them one with another on this basis, in spite of the various possibilities as to mineral composition introduced by the varying conditions of solidification, the chemical composition shown by analysis is calculated in terms of mineral composition according to one, uniform system, that is, one general assumption as to the minerals that are formed, or may be formed, from the particular magma. In this way, all igneous rocks are comparable and classifiable *inter se*, both chemically and mineralogically. The details of the procedure and the results of this system of classification cannot be gone into here, but may be looked for elsewhere.[33] It will suffice here to say that the general principles which are considered basal are the so-called " affinities " of the various basic oxides for, first silica, and second alumina, which have been given on a previous page, and which are deduced from the general knowledge of rock minerals. Carried out along the lines so laid down the results of the calculation from the data of the chemical analysis give a mineral composition which, although ideal, corresponds with the actual mineral composition in the great majority of cases.

Some years ago Iddings[34] pointed out that the density (specific gravity) of a rock as calculated from the calculated mineral composition on the assumption that the rock is holocrystalline, corresponds very closely with the actual density. This fact is of great interest: partly because of its justification of the funda-

[33] Cross, Iddings, Pirsson, and Washington: " A Quantitative Classification of Igneous Rocks," Chicago, 1903; Washington, H. S.: *U. S. Geol. Survey, Prof. Paper No. 99*, 1917. There is a considerable literature on this and other systems of the classification of rocks.

[34] Iddings, J. P.: "The Problem of Volcanism," p. 123, 1914. For a later and more detailed statement, see Iddings, *Amer. Jour. Sci.* (4), xlix, p. 363, 1920.

mental basis of the classification, and also because it thus fur-
nishes a uniform means of comparing the densities, not only of
particular rocks, but of the average rocks of different regions,
and quite irrespective of such factors as those due to porosity
or the presence of glass. Following the suggestion of Iddings,
I have calculated the average densities of the continents, the ocean
floors (represented by the lavas of the volcanic islands in the
Pacific and the Atlantic), and of the igneous rocks of various
countries and comagmatic regions, whose average chemical com-

TABLE IV.

Average Compositions of Continents and Ocean Floors.

	1	2	3	4	5	6	7	8	9	10
SiO₂	59.09	60.01	61.09	59.66	61.77	58.30	59.99	53.56	50.63	50.06
Al₂O₃	15.35	15.71	15.13	15.07	15.45	15.31	14.69	16.79	15.82	15.51
Fe₂O₃	3.08	2.87	3.02	3.16	3.16	3.52	2.59	4.00	4.44	3.88
FeO	3.80	3.66	3.29	3.66	2.75	3.74	4.40	5.33	5.79	6.23
MgO	3.49	3.15	3.46	3.60	2.63	3.51	3.75	4.66	5.79	6.62
CaO	5.08	4.79	4.86	4.96	4.49	5.10	5.02	7.57	7.36	7.99
Na₂O	3.84	3.89	4.07	3.72	4.09	4.84	3.49	3.57	4.27	4.00
K₂O	3.13	3.06	2.68	3.39	3.22	3.28	3.02	2.32	2.31	2.10
H₂O	1.14	1.01	1.04	1.24	1.23	1.26	1.19	0.93	1.47	1.16
TiO₂	1.05	1.01	0.56	0.83	0.68	0.84	1.01	0.87	1.63	1.96
P₂O₅	0.30	0.26	0.11	0.23	0.12	0.20	0.26	0.17	0.43	0.25
MnO	0.12	0.10	0.12	0.08	0.10	0.07	0.15	0.03	0.04	0.15
Incl	0.48	0.19	0.16	0.14	0.04	0.17	0.13	....	0.07	0.08
	100.00	99.71	99.59	99.70	99.75	100.14	99.70	99.80	100.05	100.00

1. Earth. (5179 anals). Dens.=2.77. Elev. = +2252 feet.
2. North America. (1709 anals). Dens. =2.75. Elev. =1888 feet.
3. South America. (138 anals). Dens. =2.72. Elev. =2078 feet.
4. Europe. (1985 anals). Dens. =2.75. Elev. =939 feet.
5. Asia. (114 anals). Dens. =2.72. Elev. =3189 feet.
6. Africa. (223 anals). Dens. =2.77. Elev. =2021 feet.
7. Australia. (287 anals). Dens. =2.79. Elev. =805 feet.
8. Antarctica. (103 anals). Dens. =2.79. Elev. =? feet.
9. Atlantic floor. (56 anals). Dens. =2.85. Depth = −13,500 feet.
10. Pacific floor. (72 anals). Dens. =2.89. Depth = −14,820 feet.

positions were calculated by Doctor Clarke from the data in
Professional Paper 99.
　　Before we discuss the densities it will be well to examine
the average chemical compositions of the different continents and
ocean floors, the data for which are given in Table IV. It will
be seen that they vary considerably the one from the other, as
well as from the general average of the earth's crust. Taking,
for example, silica, the most abundant constituent, its percentages
for North and South America, and especially for Asia, are de-
cidedly above that of the earth's crust as a whole, while those

for Europe and Australia are only slightly above this. On the
other hand, the silica percentages for Africa and Antarctica, and
still more for the Atlantic and the Pacific floors, are very notably
lower.[35]   There is little difference, comparatively, in the figures
for alumina, the alkalies, and the minor constituents, but those
for the iron oxides, magnesia, and lime are distinctly lower in
those cases where silica is higher and higher where this is lower.

The continental and oceanic averages shown above represent,
in fact, different comagmatic regions on a large scale but in con-
cise form.   Though the data for some of them, as Asia, South
America, Africa, and Antarctica, are not numerous enough to be
wholly satisfactory, yet there would seem to be no valid reason
for doubting that, taken as representing broadly the general
chemical compositions of the larger structural divisions of the
earth's surface, they may safely be assumed to give us a fairly
trustworthy idea of the relations between them.   In any case,
they are the only large body of data that we have available, so
let us use them provisionally and see to what results their con-
sideration may lead.

Before doing this, however, it will be as well to devote a
few words to the average density of the crust as a whole, as this
is an important factor in the consideration of isostasy, to be taken
up later.   It will be seen from the table that the average density
of the crust is calculated, from the average chemical composition,
to be 2.77.   An average might be arrived at by considering all
the determinations of specific gravity of rock specimens that have
been made by the ordinary physical methods, and that are found
abundantly in the literature.   An average thus arrived at would
seem to suffer from several disturbing factors that are eliminated
by the method based on the chemical averages.   Thus, it would
include the densities of many lavas that are more or less glassy,
which are decidedly lighter than holocrystalline rocks, and which,
furthermore, are surficial rocks, not found at any consider-
able depth beneath the surface.   It would also be seriously affected
by the porosity of the surface rock specimens; and at great
depths this must be very largely, or wholly, done away with by
the pressure of the superincumbent crust, as shown by Van Hise
and others.   On the other hand, however, the density determina-

[35] If the analyses of the rarer rocks are disregarded, the density of the
Atlantic floor is about 3.05 and that of the Pacific is about 3.10.

tions are probably more equably distributed among the various kinds of rocks than are the chemical analyses, which may reasonably be expected to include a possibly undue proportion of " interesting " and rarer types of rocks, as has been mentioned.

It is impossible at present to evaluate the relative influences of these several factors, but I might incidentally express my surprise that such a simple means of arriving at an estimate of the average density of the rocks of the earth's crust as is here suggested does not seem yet to have been attempted—at least nothing

FIG. 3.

Elevations and densities of the continents.
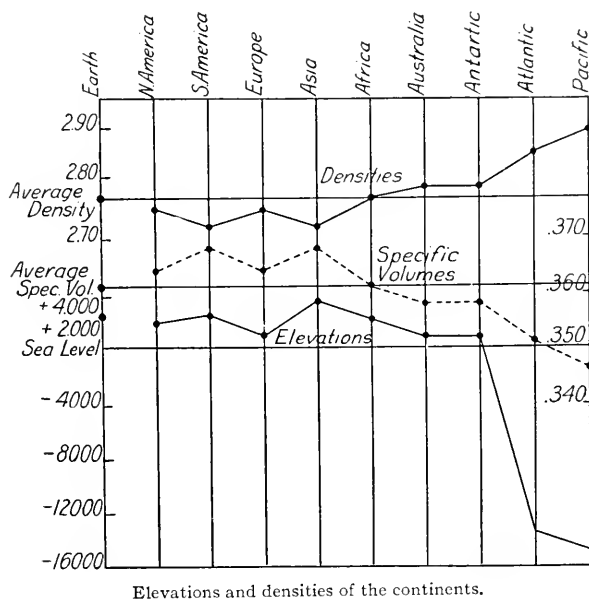
seems to have been published on the subject. An estimation that I am now making along this line is not yet complete enough for publication in this paper, but will be given later elsewhere.

On the whole, after due consideration of the several factors involved, I am inclined to put much greater weight on the final result arrived at from the averages of the chemical compositions. This, also, is subject to certain possible corrections in the future. It would seem to be probable that it is somewhat too high, as it does not include any, or at least a proportionate, number of analyses of many large areas which are almost certainly generally

granitic, and therefore relatively light. This applies to the interiors of Asia, South America, Australia, and probably Africa, to mention the larger divisions, and also to smaller ones, such as Spain, Egypt, South Africa, the Greater Antilles, and others. It is impossible now to estimate the magnitude of this correction.

On the other hand, if we are dealing with the rocks of the crust to any (humanly) considerable depth, such as the ten miles assumed by Clarke, and which might justly be placed at twenty or more, we meet with the possibility of a correction in the other direction, that is, toward a higher density. This conclusion is based on the ideas of Daly and others as to the existence of a basaltic substratum beneath the dominantly granitic outer shell, that is brought about by " gravitative adjustment."

Balancing up these conflicting factors, I am inclined to place the average density of the crust at about 2.75, at least for the uppermost shell, while that of 2.80 would probably be nearer the truth for the average of any considerable depth, such as twenty or more miles. In the present state of our ignorance and the paucity of our data, however, it would seem to be wisest to accept the figure given by the many analyses available, and assume a density of 2.77 as that of the earth's crust.

Geodesists have assumed a density of 2.67 for their studies of isostasy, as will be noted elsewhere. They take into their calculations, however, only the extremely superficial layers, including such strata as soil and light sedimentary deposits. As will be mentioned later, I am inclined to think that this estimate is much too small, and that the basis of their calculations should be a considerably higher density. That of 2.77, here assumed, or possibly better 2.75, would seem to be the best available under the circumstances.

ROCK DENSITIES AND ELEVATIONS.

With the analyses in Table IV are given the calculated densities and the average elevations of the continents and the depths of the ocean floors referred to sea level. The general relations are graphically expressed in Fig. 3. The lowest graph is that of elevations, the uppermost is that of densities, while the intermediate one is that of specific volumes, or reciprocals of the densities, which serves better to bring out the parallelism. The sequence of the continents and oceans is arbitrary.

It will be evident from the Table IV and from the graphs that there is a close relation between the average densities of the continental masses and of the ocean floors and their average elevations or depressions.   They stand in inverse relation to each other; that is, the higher portions of the earth's crust are composed of the lighter rocks, and the lower portions of the heavier.   When it is remembered that these relations are shown by a very considerable number of averages based on a very large number of trustworthy analyses (the largest so far available), from all parts of the earth, the correspondences are too striking to be explicable by an appeal to chance or coincidence.   This is even more obvious when we come to consider the relations in greater detail, as we shall do presently.

In discussing this subject it must be kept in mind that we are dealing with the averages of large areas and of many analyses, so that small and local details are lost.   Thus a number of volcanoes show flows of heavy basalt covering lower flows or inner cores of lighter rhyolite or andesite.   Again, it is not uncommon to find sheets of heavy basalt capping plateaus or forming the summits of their mountain remnants.   But such apparent contradictions to the general law shown above are but local and minor details, insignificant as compared with the immeasurably greater masses of which they form but topographic surface features.

The general relations between rock density and elevation are also, and possibly more strikingly, seen when they are presented in greater detail, as is done in Figs. 4 and 5.[36]   These are based on the average densities calculated from the average chemical compositions of the rocks of different countries and regions, as determined by Doctor Clarke.   These represent the general elevations and corresponding average densities along two zones around the earth, the one roughly between Lat. 40°–50° N. and the other between Lat. 10°–20° S.   It is to be understood that the graphs are much generalized, representing average densities and elevations, so that there is little detail.

The outer circle is that of sea level, and the irregular line that crosses it is a generalized graph of the land elevations and the ocean depths.   Though the positions in longitude are approxi-

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[36] For the suggestion of this method of presentation I am indebted to Dr. L. H. Adams, of the Geophysical Laboratory.

mately correct, the vertical scale of these is not that of the earth, as represented by the sea-level circle, but the heights and depths are very greatly exaggerated; otherwise the differences would not be perceptible in any practicable illustration. The portions of the land surface are, however, all drawn to the same (exaggerated) vertical scale, while that of the ocean depths is one-half of this. The elevations shown for the interiors of South America, Africa, and Australia are the continental elevation averages, as given by Murray.

The inner circle is that of the average specific volumes $\left(\frac{1}{2.77} = 0.361\right)$, and the inner broken line, made up of arcs, is that of the average specific volumes of the portions of the earth's crust radially above the successive small arcs. Specific volumes (the reciprocals of the densities) are used instead of densities because the relations are brought out more clearly and immediately by the parallelism with the elevation graph shown by the former. The arc portions of the specific volume graphs in solid lines are the ascertained averages, while portions that are unknown, because of the absence of exposures of igneous rocks or for other reasons, are indicated by dotted arcs, their radial distance being roughly estimated, so far as is possible. These various arcs are connected by radial dotted lines.

The centre of the circles is the locus of the axis, seen from the North Pole, and is at the same time the zero point for the two graphs.

The graphs show the correspondence between elevation and specific volume so clearly that it is scarcely necessary to go into a detailed description; yet a brief summary of the northern zone may be of interest. This represents the conditions around a zone, which extends roughly between 40° and 50° North Latitude, varying somewhat north or south so as to include available data and complete the circle. The data on which the graphs are based are given in Table V.

Let us take a little journey around the earth along the northern zone (Fig. 4). Beginning at the Pacific coast the land gradually rises across California to the high plateau of Nevada and Utah, culminating in Colorado. Thence it slopes gradually down, across the Great Plains (Kansas) to the Mississippi Valley. Along this slope practically no igneous rocks are met with, except for sporadic and little-studied occurrences in the Ozark ridge. The slight rise

seen in the Mississippi basin is the level of the rocks of the Lake
Superior region (Minnesota, Wisconsin, Michigan). East of this
(Kentucky) few igneous rocks are known except those men-
tioned above, and the land slopes gradually up to the Appalachian

TABLE V.

*Average Densities, Specific Volumes, and Elevations.**

	Density	Spec. Vol.	Average Elevation
			Feet
Earth	2.77	.361	+2252
North America	2.75	.364	1888
United States	2.75	.364	2500
South America	2.72	.368	2078
Europe	2.75	.364	939
Asia	2.72	.368	3189
Africa	2.77	.361	2021
Australia	2.79	.358	805
Antarctica	2.79	.358	?
Atlantic floor	2.85	.351	−12800
Pacific floor	2.89	.346	−15400
Zone 40°–50° North Latitude.			
California	2.742	.365	+3000
Oregon and Washington	2.773	.361	2500
Utah and Nevada	2.717	.368	6000
Colorado	2.735	.366	7000
Ozark Region	2.728	.367	2000
Mich., Wisc. Minn	2.803	.357	1000
Appalachia (Penn. to Ga.)	2.749	.364	2000
New England and N. Y.	2.759	.362	750
Great Britain	3.041	.329	300
France	2.867	.349	600
Germany	2.772	.361	800
Switzerland and Tyrol	2.729	.366	5000
Austria-Hungary	2.784	.359	2000?
Urals and Caucasus	2.829	.353	2000+
Pamirs	2.72−	.368+	13000
Japan	2.723	.367	1420
Zone 10°–20° South Latitude.			
Andes	2.717	.368	6000?
East Brazil	2.745	.364	2500?
Africa (East and West)	2.77	.361	2021
Madagascar and Reunion	2.830	.353	2199
New Zealand	2.749	.364	2134

* For the hypsometric data I have consulted Murray, Scot, *Geog. Mag.*, iv, pp. 1-29, 1888;
Gannett, *U. S. Geol. Survey, Ann. Rep.* 13, ii, d. pp. 283-289, 1892; Bull. No. 274, 1906; and
other authorities.

ridge, and east of this, across New England in the graph, de-
scends to sea level.

The floor of the North Atlantic is rendered very summarily,
and the Azores and Iceland are about our only source of infor-

mation as to the composition of its floor. On the east coast of
the Atlantic the British Isles rise to but a small height (on the
average) above its surface. The average elevation of France is
slightly higher; that of Germany (which is inserted in the zone
a little out of latitude) is still somewhat higher, and thus we come
to Switzerland and the Tyrol, the culminating portion of Europe.
To the east of this, with an average elevation slightly greater than
that of Germany, lies Austria-Hungary, and then to the east

FIG. 4.

Surface relief and specific volume.
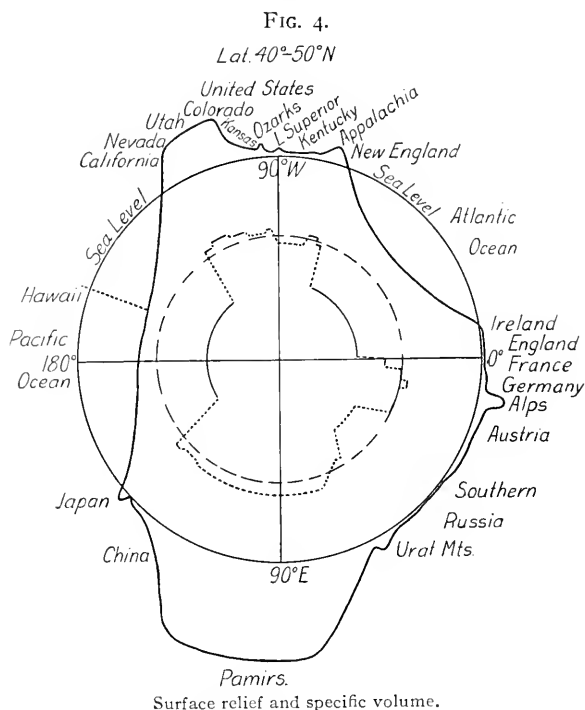
the low-lying plains of South Russia. East of these are the
Ural Mountains, and then (bending somewhat southerly) we pass
through Turkestan and Persia, and reach the very high Pamirs,
the "Roof of the World." Thence the surface slopes down across
China, rises again in Japan, and again drops to the depths of the
Pacific Ocean.

Let us now see how the rock densities, or rather the rock
specific volumes, correspond with the elevations. This inner
graph, it is to be remembered, represents the specific volumes,

that is the reciprocals of the densities, so that it is inverse to what the graph of the densities would be; that is, the heavier the average rock the nearer to the centre is it on this graph, and the lighter the farther away.

Starting with California, we find its specific volume arc above the average, and that of Nevada-Utah to the east still higher. The average of Colorado is a trifle lower, though the elevation is higher, and this is one of the very few notable exceptions to the general rule. We are ignorant of the igneous rocks beneath Kansas; they are indicated as but a little above the average, which is probably not very far wrong. There is a decided rise below the Ozark ridge (with its greater elevation), while the arc below the Mississippi Valley is represented by the small arc for the Lake Superior rocks, which are high in iron oxides and with high average density. Of the rocks below " Kentucky " (east of the Mississippi) we know little, but the Lake Superior arc is continued here because of the sporadic occurrences of some heavy peridotites in this region mentioned above. The graph rises sharply in the arc beneath the Appalachians, falling again beneath New England, which is distinctly below the average.

With the Atlantic floor we descend to an arc beneath it that is well toward the centre, as its rocks are of very high density. The arc for Great Britain is scarcely above that of the Atlantic floor, that of France distinctly higher, though still below the average, while the arc below Germany is just above the average.[37] With the Alpine and Tyrol arc we rise well above the average and here, just as in the elevation graph, we reach the culminating point of Europe. The arc beneath southern Russia (dotted) is placed at a level but slightly different from that of Great Britain because, though igneous rocks are rare in this district, there are occurrences in Volhynia of very heavy iron-bearing basalts. The arc beneath the Urals is but slightly above this, corresponding with the heavy rocks of these mountains which, it is to be remembered, are low and little more than large hills. Of the rocks of Persia and Turkestan we know but little, so the arc below this is dotted and slopes up to that beneath the Pamirs, or Central Asia. Here

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[37] The specific volume arc for Germany should be but little above that of France to correspond with the relative elevations; it appears to be much higher because very many of the German analyses of the heavier rocks (diabases, basalts, etc.), the analysis of which is most liable to error, are of very poor quality, and are therefore omitted.

again our knowledge is far from precise, so that the arc is dotted
and is placed at the level of that of the average of Asia, though it
should probably be somewhat higher.   Analyses of Chinese rocks
are few, but they would seem to be in general like those of the
Pamirs, though a trifle heavier.   The Japan arc is above that of
China, and east of this we reach the wide arc beneath the Pacific
Ocean—the lowest of all, just as its rocks are the heaviest.

After the journey around the world that we have just made
in the northern hemisphere it seems quite needless to make that in
the southern (Fig. 5).   The reader may follow the correspondence

FIG. 5.

Lat. 10°-20°S

Surface relief and specific volume.
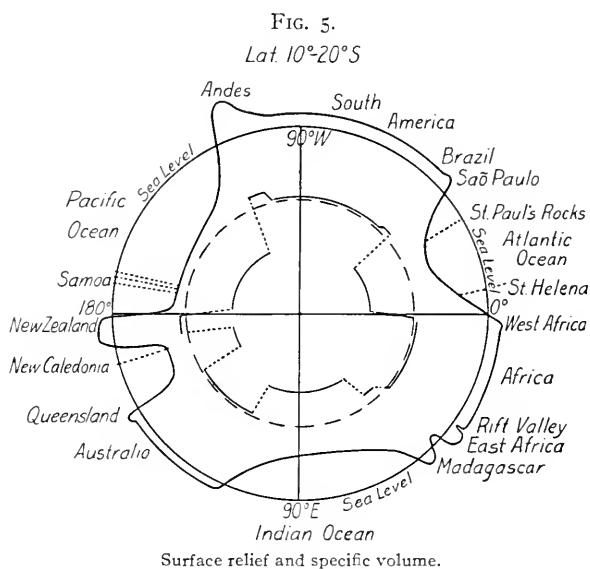
for himself, remembering that the available data along this zone
are far less numerous than along the northern; though we have
good knowledge of the rocks of Madagascar,[38] Eastern Australia
and New Zealand, and fair knowledge of those of the Andes
and western Africa and the Ethiopian Rift Valley.

ROCK DENSITIES AND ISOSTASY.

We come now to the final section of our study of the earth's
crust, the application of the data just presented to an important

[38] The average density of Madagascar is unquestionably less than that
here given, as is shown by the many more analyses now available.   The

theory regarding the stability conditions of the crust, the theory of isostasy.

As far back as 1852 J. H. Pratt suggested that there was a deficiency of gravity beneath the Himalaya Mountains, basing this on the anomalous behavior of the plumb-bob.[39] He also propounded the view that the heavier portions of the earth's surface were sinking. Later, Dutton[40] first clearly expounded the idea that the various portions of the earth's surface, being laterally unlike or heterogeneous, are in a delicately balanced condition of equilibrium, so that the lighter portions (those of less specific gravity) tend to rise, and the heavier (those of greater specific gravity) tend to sink, the various portions thus balancing each other. This theory, later called isostasy (meaning equal standing), was taken up by Hayford, and he and William Bowie, of the U. S. Coast and Geodetic Survey, and others,[41] have done much to develop it, especially as regards its application to gravity problems. While still in dispute, especially as to some details, it is a well-recognized and generally accepted geodetic theory.

It will be well to quote, in part, Hayford's definition[42] of isostasy. Assuming a condition of lateral heterogeneity, he says: " Different portions of the same horizontal stratum may have somewhat different densities, and the actual surface of the earth will be a slight departure from the ellipsoid of revolution in the sense that above each region of deficient density there will be a bulge or bump on the ellipsoid, and above each region of excessive density there will be a hollow [depression], relatively speaking. The bumps on this supposed earth will be the mountains, the plateaus, the continents; and the hollows [depressions] will be the oceans. The excess of material represented by that portion of the continent which is above sea level will be compensated for by a defect of density in the underlying material. The continents will be floated, so to speak, because they are composed of relatively light material; and, similarly, the floor of the ocean, on this supposed earth [will] be depressed because it is composed

density 2.83 represents more properly that of Reunion, and thus that of the floor of the Indian Ocean.

[39] Cf. Iddings, J. P.: " The Problem of Volcanism," p. 64, 1914.

[40] Dutton, C. E.: *Bull. Phil. Soc. Wash.*, xi, p. 51, 1889.

[41] For some references, see Iddings, *op. cit.*, p. 65.

[42] Hayford, J. F.: " The Figure of the Earth," p. 66, 1909; cf. Bowie, W.: *U S. Coast and Geodetic Survey, Special Publication No.* 40, p. 7, 1917.

of unusually dense material. This particular condition of approximate equilibrium has been given the name isostasy."

As has been noted above, in the case of northern India, it has long been known, from pendulum determinations of gravity, that in many portions of the earth the observed force of gravity does not correspond with that calculated from the form of the geoid, after making corrections for the influence of topography (such as the attraction of near-by mountain masses), and for the elevation of the station above sea level. Thus, it has long been known that gravity is, on the whole, greater over the ocean than over land areas, and this has naturally been connected with the fact that the rocks of oceanic islands are mostly basaltic, and therefore heavy.

These departures from the normal are known as " anomalies." They may be either positive, when the gravity is above the normal, or negative, when it is below. The anomalies have been studied with great care and in great detail, especially by Hayford and Bowie in the area of the United States, who have invoked the theory of isostasy to account for them. This explanation is satisfactory to a very large extent, but, as Iddings says, " There remain anomalies of density which need to be accounted for." On the whole, however, it appears that the theory of isostasy " obtains for the major features of the earth's surface." It may be suggested here (though the matter cannot be discussed), that the discrepancies may be due, in part at least, to the fact that the geodesists have taken account of the rock densities only of those portions very near the surface, mostly soils and sedimentary rocks, and have neglected the deeper-lying portions. The average density assumed by geodesists for the surface rocks is 2.67, while, as we have seen, that of the igneous rocks of the earth's crusts is 2.77 or 2.75.

It will be seen that the idea of the continental masses being composed of light material, while the ocean floors are of heavy, is by no means new. Up to the present, however, there has been no quantitative verification of this, except for the few figures covering limited areas given by Iddings. The data given above, with the graphs, therefore, are of special interest as furnishing a first approximation to a knowledge of the actual specific gravities of the various portions of the earth's crust. It is evident that they are, on the whole, and even in considerable detail, quite in harmony with the theory of isostasy. Indeed, based as these

figures are on a large number of data (the largest by far yet available) from all parts of the earth, and showing such a complete harmony between average specific gravity and average elevation everywhere, they may fairly be said to be more than coincidental, and to constitute almost a conclusive proof of the general validity of the theory of isostasy.

One further point of agreement may be mentioned. In Fig. 6 is given a map of the United States reproduced by Barrell[43] from Bowie, showing the distribution of the gravity anomalies

FIG. 6.
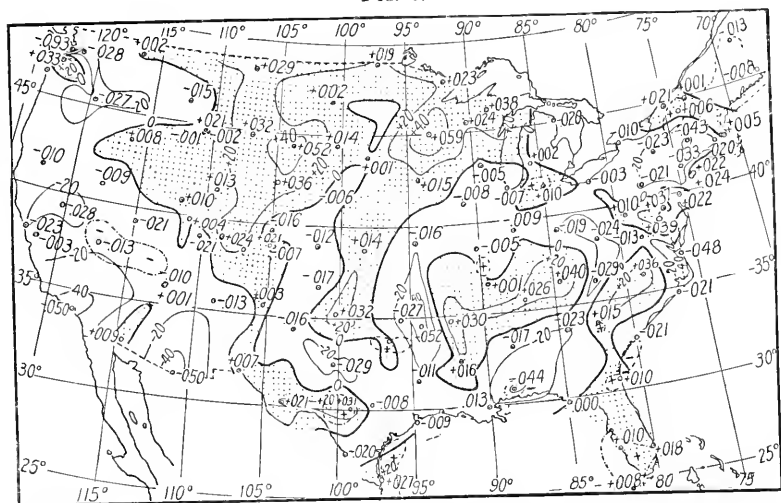
Dotted portions: Areas of positive anomaly, excess of mass. Due to surface too high or density of upper crust above mean.
Blank portions: Areas of negative anomaly, deficiency of mass. Due to surface too low or density of upper crust below mean. Gravity anomalies in the United States.

over the United States. Let us compare this with the description of the comagmatic regions of the United States (page 796). In Fig. 5 the dotted areas are those of positive anomaly (excess gravity), while those not dotted are of negative anomaly (deficient gravity).

In the extreme northeast is a small area of positive anomaly about the Adirondacks, which corresponds with the small comagmatic outlier there of the Canadian Shield, of which the rocks are above the average in specific gravity. The greater part of Maine, with its granites, of low specific gravity, shows negative anomaly, and this area is continued down along the Appalachian

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[43] Barrell, J.: *Jour. Geol.*, xxii, p. 153, 1914.

region, the rocks of which are of general low specific gravity. The small areas of positive anomaly in eastern Massachusetts, Connecticut, and New Jersey, may probably be connected with the extensive Triassic flows of heavy diabase and basalt which are so common here. Around the Lake Superior region we find an area of very high positive anomaly, which corresponds with the high specific gravity of the rocks of this region. On the other hand, in the Missouri-Arkansas-Oklahoma region is an area of pronounced negative anomaly, which corresponds with the low specific gravity of the region of the Ozark uplift. East of this, in Kentucky and Tennessee, is an area of somewhat high positive anomaly, and this is in harmony with the supposition made above that the rocks underlying this area are decidedly heavy.

Towards the west the relations become more complex, just as is the geological structure and as are the comagmatic relations. We cannot here go into details, which are reserved for a future publication, but the general area of negative anomaly covering the Colorado and Nevada-Utah plateau, consonant with the light rocks here, may be pointed out, as also the small area of high positive anomaly in Washington and Oregon, which may be connected with the very extensive flows of basalt of the Snake and Columbia rivers.

More might be said on this topic, but sufficient has been brought out here, it would seem, to show that there is a coincidence, even to very localized relations, between the average specific gravities of comagmatic regions in the United States and their gravity anomalies. Also, they appear to be too concordant to be the result of chance, so that we are justified in assuming that the two are causally related and that the theory of isostasy is thus justified.

SUMMARY.

After brief consideration of the interior of the earth, the general characters of igneous rocks are discussed, and the presence of water vapor and other gases in the magma, and its analogy with a salt solution, are pointed out. In the discussion of the mineral characters of rocks, stress is laid on the fact that the number of essential rock-forming minerals is very small. These are mostly silicates of Al, Fe, Mg, Ca, Na, and K. Any two or more of these minerals (with two exceptions) may occur together and in any proportions.

The chemical characters of igneous rocks are summarized, and the ranges and maxima of the various constituents are given. The average igneous rock is considered and, after some discussion of the sources of error involved in the calculation, a new average in terms of oxides (based on 5179 analyses) is given. The average rock is shown to be approximately a granodiorite.

The average composition of the earth's crust in terms of elements is also given. Twelve elements (O, Si, Al, Fe, Ca, Na, K, Mg, Ti, H, P, and Mn) make up 99.61 per cent. of the crust.

The elements are referred to two main groups in the periodic table: (1) The petrogenic elements, characteristic of, and most abundant in, the igneous rocks, of low atomic weight, and occurring normally as oxides, silicates, chlorides, and fluorides; (2) the metallogenic elements, rare or absent in igneous rocks, but occurring as ores, of high atomic weight, and forming in nature "native" metals, sulphides, arsenides, bromides, etc., but not primarily oxides or silicates. The suggestion is made that beneath the silicate crust of petrogenic elements is a zone essentially of nickel-iron, and beneath this a central core of the metallogenic elements. This vertical distribution is in accord with Abbot's views as to the distribution of the elements in the sun.

In igneous rocks and minerals the elements show a correlation, in that certain of them are prone to occur with others, and a similar, limited correlation is apparently true of the animal and vegetable kingdoms.

The idea of "comagmatic regions," that is, the distribution of igneous rocks in regions of chemically related magmas, is discussed, and some of these are briefly described.

The calculation of rock densities from their chemical composition is discussed, and the average chemical compositions and densities of the continental masses and oceanic floors are given. It is shown by these that the average densities of the continents, ocean floors, and various smaller regions of the earth stand in inverse relation to their elevations. The bearing of this relation of average density and elevation on the theory of isostasy is pointed out, and it is shown that the data presented are confirmative of the theory.

GEOPHYSICAL LABORATORY,
    CARNEGIE INSTITUTION OF WASHINGTON,
        June 20, 1920.

The Effect of Temperature upon the Transmission of Infra-red Radiation Through Various Glasses. GEORGE ROSENGARTEN. (*Phys. Rev.,* Sept., 1920.)—The radiation from a tungsten lamp was spread into a spectrum by the use of two rock salt prisms. When a thermopile joined to a galvanometer receives a part of such spectrum a deflection of this instrument follows. The introduction of a plate of glass into the path of the ray of light was, of course, followed in all cases by a notable reduction in the deflection of the galvanometer. The piece of glass was placed inside of an electric heater so that its temperature could be varied at will and the deflection corresponding to each temperature was noted. Blue-purple, blue-green and other colored glasses were examined for wave lengths from .001 to .005 mm. with a variation of temperature from 40° C. to 46° C. The conclusion reached is that "to within 8 $\pm$ per cent. there is no change in the transmission of the infra-red radiation through the glasses examined."

G. F. S.

The Separation of the Isotopes of Mercury. J. N. BROENSTED and G. HEVSEY. (*Nature,* Sept. 30, 1920.)—Writing from the Physico-Chemical Laboratory of the Polytechnic High School, Copenhagen, the authors announce that they have succeeded in separating partially one of the isotopes of mercury from the other. In one set of experiments 40 g. of the liquid was taken and evaporated at low pressure until one-seventh of it had passed off. The mercury vapor was condensed and its specific gravity was found to be .999980 of that of ordinary mercury, while the ratio for the part of the liquid which did not evaporate was 1.000031. This difference results from the rate of evaporation being greater for the isotope of smaller atomic weight. "After the separation every portion was distilled again in the ordinary way and the density measured after each distillation. No difference was found between these measurements, the error of measurement of density being less than one in a million." G. F. S.

Peat and Its Uses. (*U. S. Geological Survey Press Bulletin No. 459,* November, 1920.)—Devotees of the automobile and motor-boat will be glad to know that successful experiments have been made in Sweden in extracting wood alcohol from peat. The process as reported by the commercial attaché at Copenhagen, Denmark, is described in a report on peat in 1919 recently issued by the Survey. Interesting instances of the use of peat as a fuel are given in this report. A coastwise steamship company of Norway, for example, during the coal shortage, was enabled by the use of peat fuel to keep up its full sailing schedule.

Peat is used also in making up fertilizers and in preparing concentrated food for stock. Last year 69,197 tons of peat, valued at $705,532, was produced in the United States. This was a decided decrease from the production of 1918, although the peat deposits in this country are extensive.

NATURE AND EXPLANATION OF THE "MOTOR EFFECT" IN THE AJAX-WYATT FURNACE.*

BY

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Dr. Carl Hering read a paper May 3, 1907, before the American Electrochemical Society, on the limitations of resistance furnaces due to the " Pinch " phenomenon, which he was the first to observe in electric furnaces.   He read another paper May 6, 1909, before the same society, which he entitled, " The Working Limit in Electric Furnaces, Due to the ' Pinch ' Phenomenon." The writer of the present article presented a paper at the New York meeting of the Physical Society, March 2, 1907, which was published in the *Physical Review*, in June, 1907.   The paper was entitled, " Some Newly Observed Manifestations of Forces in the Interior of an Electric Conductor."

Up to the time these papers were published few if any recognized that the passage of a high-density current through a liquid conductor produced motions in the liquid.   It has since come to be recognized that when a high-density current, direct or alternating, flows in a liquid conductor, motions of the liquid of considerable magnitude are *always* produced.

The following analysis considers the nature and cause of the fluid motion which occurs at the apex of a fluid triangular conductor.   The Ajax-Wyatt furnace makes use of the fluid motion thus produced to circulate molten brass in the triangular-shaped resistor employed.   This furnace is now so well known and has been so fully described elsewhere, that further reference to it will not here be made.[1]

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* Communicated by the Author.

[1] For a description of this furnace see " The Melting of Brass in the Induction Furnace," by G. H. Clamer, *Jour. of the American Institute of Metals,* vol. xi, No. 3.

SECTION I.

DERIVATION OF FORMULA FOR CALCULATING THE MECHANICAL INTER-ACTION BETWEEN ELECTRIC CONDUCTORS WHICH FORM A TRIANGULAR CLOSED CIRCUIT.

Let a current i be induced in the circuit (see Fig. 1).

Let $H_t =$ the strength of the magnetic field at a point v on the conductor $O - Q$ which results from the conductors $O - P$ and $Q - P$.

FIG. 1.

Let $r =$ the distance from v to any point on the conductor $O - P$.

Let $d\theta =$ an elementary angle having its apex at v and its base on $O - P$.

Then:

$$dH_t = \frac{ir d\theta}{r^2} = \frac{id\theta}{r} \tag{1}$$

as

$$p = r \cos \theta = a \sin \alpha, r = \frac{a \sin \alpha}{\cos \theta},$$

hence

$$dH = \frac{i}{a \sin \alpha} = \cos \theta \; d \theta \qquad (2)$$

$$H_t = \frac{i}{a \sin \alpha} \int_0^{\theta_t} \cos \theta \; d \theta = \frac{i}{a \sin \alpha} \sin \theta_t \qquad (3)$$

H_1 is the magnetic force at v contributed by the length $W - P$ of the side $O - P$.

Let H_2 be the magnetic force at v contributed by the length $O - W$ of the side $O - P$.

Then, as above:

$$dH_2 = \frac{i}{a \sin \alpha} \cos \theta_1 \; d \theta_1$$

where θ_1 is the angle r makes with $p:$

$$H_2 = \frac{i}{a \sin \alpha} \int_0^{\frac{\pi}{2} - \alpha} \cos \theta_1 \; d \theta_1 = \frac{i}{a \sin \alpha} \sin \left(\frac{\pi}{2} - \alpha \right) = \frac{i}{a} \frac{\cos \alpha}{\sin \alpha}$$

or

$$H_2 = \frac{i}{a \tan \alpha} = \frac{i}{a} \cotan \alpha \qquad (4)$$

The total magnetic force at the point v contributed by the side $O - P$ is $H = H_1 + H_2$, or

$$H = H_2 + H_1 = \frac{i}{a \sin \alpha} (\cos \alpha + \sin \theta_t) \qquad (5)$$

To find the force H^1 contributed by the side $Q - P$, we merely have to change in Eq. (5) a into b and α into β, when we have:

$$H_t = H + H^1 = i \left[\frac{1}{a \sin \alpha}(\cos \alpha + \sin \theta_t) + \frac{1}{b \sin \beta}(\cos \beta + \sin \theta_t') \right] \qquad (6)$$

To be able to obtain numerical results, it is necessary to express $\sin \theta_t$ and $\sin \theta_t'$ in terms of the known quantities a, L, α and b, S, β.

This may be done as follows:

Call E the distance from v to P.

$p = E \cos \theta_t = a \sin \alpha$, hence

$$\cos \theta_t = \frac{a \sin \alpha}{E} \tag{7}$$

$$\cos^2 \theta_t = \frac{a^2 \sin^2 \alpha}{E^2},$$

and

$$1 - \cos^2 \theta_t = \frac{E^2 - a^2 \sin^2 \alpha}{E^2},$$

or

$$\sin^2 \theta_t = \frac{E^2 - a^2 \sin^2 \alpha}{E^2} \tag{8}$$

Also,

$$E^2 = (L - a \cos \alpha)^2 + p^2 = (L - a \cos \alpha)^2 + a^2 \sin^2 \alpha$$

from which we find:

$$E^2 = L^2 - 2aL \cos \alpha + a^2 \tag{9}$$

Putting this value of E^2 in (8), we derive finally:

$$\sin \theta_t = \frac{L - a \cos \alpha}{[a^2 + L (L - 2a \cos \alpha)]^{1/2}} \tag{10}$$

By changing L into S, a into b, and α into β we also have:

$$\sin \theta_t' = \frac{S - b \cos \beta}{[b^2 + S (S - 2b \cos \beta)]^{1/2}} \tag{11}$$

Place these values of $\sin \theta_t$ and $\sin \theta_t'$ in Eq. (6) and we obtain:

$$H_t = i \left\{ \frac{1}{a \sin \alpha} \left[\cos \alpha + \frac{L - a \cos \alpha}{[a^2 + L (L - 2a \cos \alpha)]^{1/2}} \right] + \right.$$

$$\frac{1}{b \sin \beta} \left[\cos \beta + \frac{S - b \cos \beta}{[b^2 + S (S - 2b \cos \beta)]^{1/2}} \right] \tag{12}$$

Equation (12) expresses the magnetic force at any point v on the side $O - Q$ of triangular circuit in which this force is due to the current in the sides $O - P$ and $Q - P$.

We shall treat the case in which the triangle is equilateral. Then $\beta = \alpha$ and $S = L$, and Eq. (12) becomes

$$H_t' = \frac{i}{\sin \alpha} \left[\frac{1}{a} \left(\cos \alpha + \frac{L - a \cos \alpha}{\sqrt{a^2 + L (L - 2a \cos \alpha)}} \right) + \right.$$

$$\frac{1}{b} \left(\cos \alpha + \frac{L - b \cos \alpha}{\sqrt{b^2 + L (L - 2b \cos \alpha)}} \right) \tag{13}$$

The *mechanical* force which acts to move an element of length Δa of a conductor carrying a current i acts at *right angles* to the length of the element Δa and is numerically equal to the strength of the magnetic field, to the current i carried by the element of the conductor, and to the length of the element.   Or:

$$\Delta F = i \Delta a H, \tag{14}$$

(Consult Maxwell: "Treatise on Electricity and Magnetism." Vol. II, Arts. 522, 597, 507.)

Put the value Ht' from Eq. (13) in Eq. (14) for Ht and we obtain the mechanical force which acts to move at *right angles to itself* the element of the conductor, Δa.   Thus:

$$F' = \frac{i^2 \, \triangle a}{\sin \infty} \left[\frac{\cos \infty}{a} + \frac{L - a \cos \infty}{a \, \sqrt{a^2 + L\,(L - 2a \cos \infty)}} + \frac{\cos \infty}{b} + \right.$$
$$\left. \frac{L - b \cos \infty}{b \, \sqrt{b^2 + L\,(L - 2b \cos \infty)}} \right. \tag{15}$$

For convenience call:

$$\frac{i^2 \, \triangle a}{\sin \infty} = C; \quad \frac{\cos \infty}{a} = A;$$

$$\frac{L - a \cos \infty}{a \, \sqrt{a^2 + L\,(L - 2a \cos \infty)}} = B; \quad \frac{\cos \infty}{b} = A';$$

$$\frac{L - b \cos \infty}{b \, \sqrt{b^2 + L\,(L - 2b \cos \infty)}} = B'$$

Then write:

$$F' = C \, (A + B + A' + B') \tag{16}$$

The two terms A, B, express the contribution to the force given by the side $O - P$; and the two terms, A', B', express the contribution to the force given by the side $Q - P$.   There is no action to move the element Δa by the side $O - Q$.

NUMERICAL RESULTS CALCULATED BY THE AID OF EQUATIONS (15) AND (16).

We assume the following values for the constants:

$i = 800$ electromagnetic C.G.S. units $= 8000$ amperes.
$i^2 = 64 \times 10^4$; $\triangle a = $ unit of length $= 1$ cm.
$L = 40$ cm.; $\infty = \beta = 60° = \dfrac{\pi}{3}$ radians.

The force is calculated for values of a and b given in the table below:

a cm.	b cm.	A	B	A'	B'	C	F' dynes	F' kilograms
2.5	37.5	.200	.4	.0133	.0146	739×10^3	463900	0.473
5.0	35.0	.100	.1988	.0143	.0170	739×10^3	243870	0.249
7.5	32.5	.0666	.1313	.0153	.0199	739×10^3	172200	0.176
10.0	30 0	.050	.0971	.0167	.0231	739×10^3	138100	0.141
12.5	27.5	.040	.0762	.0181	.0269	739×10^3	119000	0.121
15.0	25.0	.0333	.0619	.0200	.0314	739×10^3	108300	0.110
20.0	20.0	.025	.0433	.0250	.0433	739×10^3	101000	0.103

SECTION II.

PRESSURE PRODUCED IN A NARROW STRIP WHICH CARRIES AN ELECTRIC CURRENT.

Let $a - b$ (Fig. 3) be a plane on the middle line through the strip normal to its greater width and parallel with its length, assumed very great as compared with the other dimensions of the strip.

The force of attraction of a linear conductor of infinite length carrying a current i_c, upon a unit length of a parallel conductor carrying a current i and distant r from the first, is:

$$F = \frac{2ii_c}{r} \tag{1}$$

(Maxwell, "Treatise on Electricity and Magnetism." Vol. II. Art. 495.)

Let I = total current carried by the strip.
W = thickness of strip.
$R_t = 2R$ = width of strip.

The current i_t, carried by a portion of the strip of width $2r$ is:

$$\frac{i_t}{I} = \frac{2r}{2R}$$

Hence:

$$i_t = \frac{r}{R} I = \frac{2r}{R_t} I \tag{2}$$

The current carried by a strip of width dr is given by:

$$\frac{di}{\frac{1}{2}I} = \frac{dr}{R}$$

Hence :

$$di = \frac{I}{2R} \, dr = \frac{I}{R_t} \, dr \tag{3}$$

The force which attracts a unit length of the element dr carrying the current di is :

$$dF = -\frac{2dii_t}{r} = -\frac{2 \cdot I \frac{dr}{R_t} \cdot 2 \frac{r}{R_t} I}{r} = -\frac{4I^2}{R_t^2} \, dr \tag{4}$$

The minus sign signifies that the force diminishes as r increases and that it acts toward the plane $a - b$.

The intensity of the force, or force per unit area, is :

$$\frac{dF}{W} = dg = -\frac{4I^2}{WR_t^2} dr \tag{5}$$

The intensity of the force at distance r from the plane $a - b$ is :

$$g = -\frac{4I^2}{WR_t^2} \int_{r}^{\frac{1}{2}R_t} dr = \frac{2I^2}{WR_t^2} \left(2r - R_t \right) \tag{6}$$

The pressure, which is directed chiefly toward the plane $a - b$ is, on the surface of this plane :

$$g_\rho = -\frac{2I^2}{WR_t} \tag{7}$$

g_ρ is the pressure per unit area which acts upon the median plane $a - b$. In calculating this pressure, if I is taken in C.G.S. electromagnetic units, and W and R_t in centimetres, g_ρ will be in dynes per square centimetre.

NUMERICAL CALCULATION OF THE PRESSURE.

For constants choose :

$I = 800$ electromagnetic C.G.S. units $= 8000$ amperes.
$W = 1.5$ c.m.; $R_t = 7.6$ c.m.; $I^2 = 64 \times 10^4$

Then, by equation (7), the pressure at the plane $a - b$ is :

$$g_\rho = -\frac{2 \times 64 \times 10^4}{1.5 \times 7.6} = -112280 \text{ dynes per cm.}^2$$

the minus sign meaning that this force is directed toward the median plane.

The *total* force which acts per centimetre length of the strip on the median plane is:

$$112280 \times 1.5 = 168420 \text{ dynes.}$$

Expressed in kilograms these pressures are, respectively, 0.1145 and 0.1717.

By means of equation (6) we find the intensity of the force to have the following values at distances r, given in column 1, in the table below:

TABLE I.

r in cm.	g in dynes	g in kilos	$Wg = 1.5g$ in kilos	g in lbs. per sq. inch
0	112280	0.1145	0.1717	1.629
0.5	97530	0.0995	0.1492	1.416
1.0	82760	0.0840	0.1260	1.195
1.5	68000	0.0693	0.1040	0.986
2.0	53200	0.0543	0.0814	0.773
2.5	38420	0.0392	0.0588	0.558
3.0	23650	0.0241	0.0361	0.343
3.5	8868	0.0090	0.0135	0.128
3.8	0	0	0	0

CURVE 1.

Plot of Values in Table I
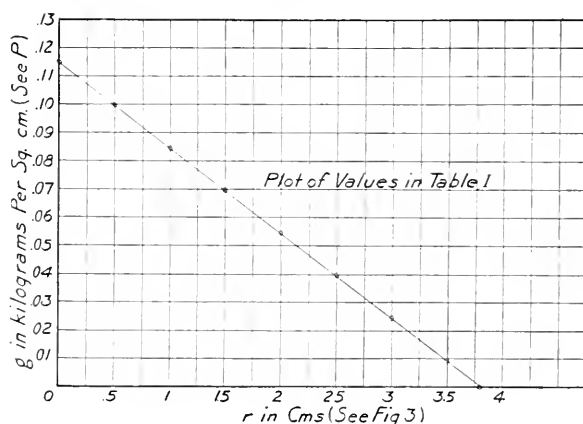
SECTION III.

NECESSARY ASSUMPTIONS MADE IN DERIVING EQUATION (15), SECTION I.

In order to derive a formula to calculate the forces set up by electromagnetic action upon one small portion of a conductor by the remainder of the circuit, it is necessary to assume the circuit

to have some simple geometrical form. The geometrical form which most closely approximates the actual case which we have to consider and which can be handled mathematically, is an equilateral triangle.

If in equation (6) we place $a = O$ and $b = 40$ the equation gives H_t equals infinity. This does not show that the equation is unsuited for calculating the magnetic force, because in the actual case the current does not flow toward, and from, a mathematical point where two straight lines meet in an angle, but flows round a bend of considerable radius of curvature; and if it were possible to take this curvature into account in the calculation it would be found that the force is finite and not far different in value from the force which is calculated at a distance of 4 or 5 centimetres from an apex of the triangle.

It is further necessary to assume, to make a calculation practicable, that the entire current flows along a mathematical line located on the axis of the conductor. This is indicated by the triangle drawn in dotted line in Fig. 2. In the actual case the force which acts on current-elements lying along the inside of the triangle will exceed, by a small amount, the force acting on current-elements which lie along the outside of the triangle. While in deriving a formula, it is necessary to assume that the current flows in a triangle, the small value of the terms, A', B', as compared with the terms A, B, in equation (16), shows that only a small deviation from the actual conditions is made by assuming the circuit of triangular form. Thus, for $a = 2.5$, $A' + B' = 0.0279$, and $A + B = 0.6$. $A' + B'$ contribute thus only about 4.4 per cent. toward the whole force acting It is, therefore, of small consequence upon the result whether we assume the side $Q - P$ (Fig. 1) is a straight line which completes the triangle or whether this side is a semi-circular arc.

Since the actual conductor is 7.6 cm. deep in a direction perpendicular to the plane of the drawing (Fig. 2) and only 1.5 cm. wide, the *difference* between the force acting upon the outside triangular surface and the force acting upon the inside triangular surface is very small. At a distance of 7.5 cm. from the apex of the angle shown in dotted line, I estimate this difference to be about 0.036 kilogram, or 0.00473 kilogram per cm. The difference in pressure between the outside edge and the median plane of the conductor, in the direction vertical to the plane of the

drawing, due to the mutual attraction of the current elements
in the conductor, is 0.1145 kilogram per cm. Thus the effective
pressure-difference over a plane *normal* to the length of the
conductor, due to the mutual attraction of current-elements, is
in the neighborhood of 24 times the pressure-difference over the

FIG. 2.

Ba th

60°

0.103
0.106
0.110
0.121
0.141
0.176
0.249
0.473

Force in kilograms
acting on each unit
of length of
conductor at points
indicated
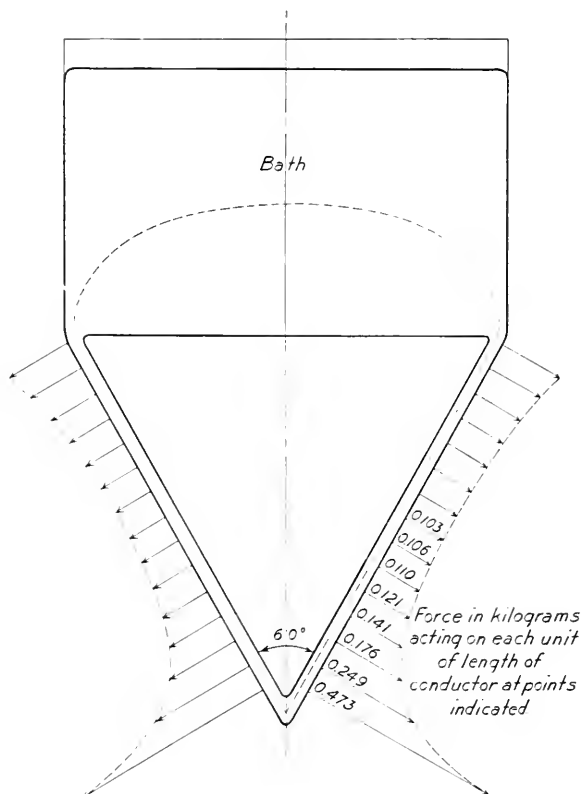
plane which would be set up by the mutual repulsion between the
two limbs of the conductor at a distance of 7.5 cm. from the apex
of the triangle represented in dotted line in Fig. 2.

The forces of mutual repulsion between any two sides of the
triangle are greatly modified in the actual case by the field which
results from the leakage lines from the transformer. This cir-
cumstance alone will greatly modify any estimate based on calcu-

lation of the repellent forces and the pressure-difference forces produced by the action of one limb of the circuit upon another.

NECESSARY ASSUMPTIONS MADE FOR DEDUCING EQUATION (6), SECTION II.

In deducing Eq. (6) it has been assumed that the force of attraction which acts upon a strip dr infinitely thin, carrying a current element di, acts only toward, and normal to, the median plane $a - b$ (Fig. 3). In reality, a force of attraction is also

FIG. 3.
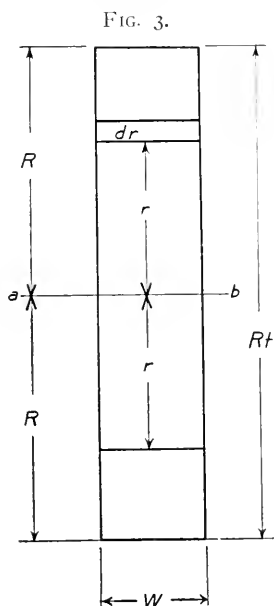
exerted between opposite ends of such strip. Thus the actual force on the current element di is the resultant of two components, one very much smaller than the other. If the integration were made for this resultant force (a very complicated process) it would be found that the pressure is not quite normal on the plane $a - b$ but is directed slightly toward the centre longitudinal axis of the conductor. If the conductor had a square cross-section, so that $W = Rt$, then there would be as much pressure at its centre directed along the horizontal as along the vertical (Fig. 3). The intensity of the force at the centre would be then more nearly represented by the formula, $g = \dfrac{I^2}{S}$, where S is the area of the

cross-section of the conductor. However, if W is small as compared with R_t, as in the actual case, Eqs. (6) and (7) give the intensity of the force to a very close approximation and may be used safely to calculate the pressure per unit area set up by the mutual attraction of the current elements in the single conductor.

As is shown, tendency to fluid-motion, which results from · mutual attraction of current elements, depends upon difference in pressure between two points on a plane through the conductor normal to its length. This difference in pressure between centre and edge of the strip-conductor, due to the mutual attractions of current elements in the conductor, can be calculated with good precision by Eqs. (6) and (7). With 8000 amperes this pressure-difference will be, as shown, as much as 1.6 pounds per square inch.

Section IV.

NATURE OF THE HYDRODYNAMIC FORCES DEVELOPED BY THE ELECTRO-DYNAMIC FORCES WHICH ARISE FROM THE ACTION OF THE ENTIRE CIRCUIT UPON ANY SHORT SECTION OF THE LENGTH OF THE CONDUCTOR.

To understand the nature of these forces, conceive the V-shaped conductor to lie in a vertical plane, with one limb of the conductor in a horizontal position, as drawn in Fig. 4. Conceive further that the horizontal limb of the conductor is divided by planes normal to the length of the conductor-limb into sections separated from each other by the unit of length; in this case one centimetre. Conceive these planes to be made of thin, solid-metal sheet. The conductor limb will now be divided up into sections a, b, c, d, etc., which are 1 cm. wide, 1.58 cm. high and 7.6 cm. deep. Take the data from Fig. 2, Section I, and draw a curve A, C, B (Fig. 4), such that lines drawn from the middle of the lower side of each of the sections a, b, c, d, etc., *normal* to this lower side and terminating in the curve, represent by their length and direction the magnitude and direction of the average pressure exerted upon the fluid contained in a section 1 cm. long, 1.58 cm. high, and r cm. deep. Thus, these lines represent both in respect to magnitude and direction the normal pressure *per cm.*^{2} upon the lower side $P_1 - X_1$ of the limb of the conductor. In Fig. 4 these lines have been drawn so that a length of 1 cm. represents a

pressure of 0.01 of a kilogram. If we conceive the pressure acting upon the fluid in each compartment, a, b, c, d, etc., to be uniformly distributed over each horizontal layer of the fluid in each compartment, the fluid will be everywhere in equilibrium on account of the reaction of the walls of the compartment, and it will be quiescent.

We may, however, conceive that the forces represented as acting upon the fluid in compartments a, b, c, d, etc., are due *not* to an electric current, but *to the action of gravity* upon the fluid

FIG. 4.

Force on Fluid in Channel
1 CM. Long 1.58 CM. High and
1 CM. Deep See P.I, Sec. IV

Forces f_1, f_2, f_3, etc. Are The Pressure Forces Per $\overline{CM}^2$ Which are Calculated As Acting At The *Center* of Compartments a, b, c, etc. Respectively. Forces S_1, S_2, S_3, etc Are The Pressure Forces Per $\overline{CM}^2$ Which Are Calculated As Acting At The Left Side on the Bottom of Each Compartment a_1, b_1, c_1 etc Respectively. Subtracting S_2 From S_1 Gives The Force Which Acts From Compartment A To Compartment B At Bottom Edge And Similarly For The Others

in each of these compartments. To have the forces acting upon the fluid in the different compartments of different magnitudes, we have only to conceive that the fluid in the different compartments has different densities. Thus the density of the fluid in compartment a, for example, to give a pressure of 0.1 kilogram on the lower side of this compartment, would be:

$$\delta_a = \frac{\text{Pressure per cm.}^2}{\text{Acceleration of gravity x volume}} = \frac{100\ (980)}{980\ \text{x}\ 1^2\ \text{x}\ 1.58} = \frac{100}{1.58}$$

The density for compartment b would then be:

$$\delta_b = \frac{54}{100}\ \delta a,$$

and similarly for the other compartments.

With these graded densities of the fluid in the different compartments, the pressure-forces will be in all respects identical to the forces which are produced on a uniform fluid by the repellent action of the current.

The well-known laws of the pressure of a fluid in a vessel are:

1. "The pressure in each layer is proportional to the depth."

2. "With different liquids and the same depth, the pressure is proportional to the density of the liquid."

3. "The pressure is the same at all points of the same horizontal layer." (*Ganot's Physics,* art. 98.)

According to this third law, there will be at the very *bottom* layer of the fluid in compartment *a,* a pressure normal to partition *3* at its bottom point, equal to a force of 0.1 kilogram per cm.^{2} At the *very top* layer of the fluid in compartment *a,* there will be zero pressure on the partition. But in compartment *b* there will also be zero pressure on partition *3* at the *very top,* and at the very botom layer a pressure of 0.054 kilogram per cm.^{2} This pressure, however, acts in the *opposite* direction to the pressure on the bottom of the partition, which has place in compartment *a.* Thus there is a *resultant* pressure at the *very bottom edge* of the partition between compartments *a* and *b* which is equal to 0.1 − .054 = 0.046 kilogram per cm.^{2}

What is true of sections *a* and *b* can be applied to all the other sections. The resultant hydrostatic pressures at the very bottom edge of all the partitions *3, 4, 5, 6,* etc., are given in Fig. 4.

Assume now that the bottom edge of partition *3* is suddenly raised a small distance and that the top edge is simultaneously lowered a small distance, whereby a slot is opened below and above the partition, suddenly putting compartments *a* and *b* into communication. It is plain that the denser fluid in *a* would flow through the bottom slot into *b,* and the less dense fluid in *b* would flow in the opposite direction through the upper slot into *a.* This fluid motion would continue if *gravity alone* were acting, until the fluid in *a* is evenly divided between compartments *a* and *b,* and likewise with the fluid in *b.*

In the case of the forces set up by electromagnetic action, the fluid is in reality all of the same density, but immediately any fluid leaves a compartment and moves to the right, it is subjected to a *less* force; that is, it acts as if, in the gravitational case, it lost density; and any fluid which enters a compartment

toward the left is subjected to a greater force; that is, it acts as if, in the gravitational case, it gained density. The result of this is that, in the actual case, where the normal pressure-forces upon the fluid are due to the repulsion of the current in the rest of the circuit, and where these pressure-forces diminish in magnitude as the distance along the conductor from the apex of an angle increases, the fluid is acted upon by hydrodynamic forces which not only cause it to circulate, but *to circulate continuously*.

We now only have to conceive that all the partitions are removed, and we shall have, in the actual case, a stream of the fluid moving along the side $P_1 - X_1$ of the conductor, and a returning stream moving along the side $X_2 - P_2$. The total hydrodynamic pressure-difference between any two points along the conductor which acts to maintain this flow is given by taking the difference of the normal pressures produced by electrodynamic forces between these two points. This pressure-difference, for example, between a point located on the middle of the bottom of compartment a and on the middle of the bottom of compartment r is:

$$0.1000 - 0.0126 = 0.0874 \text{ kilogram per cm.}$$

The power expended in moving the fluid from one point to another along the conductor will be $P = (F_1 - F_2)V$, namely, equal to the difference in the pressure between two points times the velocity, or grams per second, of fluid which crosses in one direction any section of the conductor between the two points where the pressures are F_1 and F_2. This power is, of course, derived from the transformer, and, due to the motion of the fluid, the conductor will develop a back E.M.F., so that a greater E.M.F. will be required to maintain the current than would be the case if the conductor were a solid instead of a fluid which can move, and in moving do work.

We can now give a definition of the " motor-effect," which is a reality.

When by any geometrical disposition whatever of an electric circuit, in which the conducting material is a fluid capable of free motion, normally acting electrodynamic forces arise in any section of the circuit which vary in magnitude from one point to another over a length measured along the axis of the conductor, there also arise hydrodynamic forces which can impress

motions on the fluid substantially parallel to the longitudinal axis of the conductor.

Actual fluid motions which result from these hydrodynamic forces are designated, for brevity, " *The Motor-effect.*"

The magnitude of the forces which give rise to a motor-effect may be ascertained as given in Fig. 2. The motor-effect which results, namely, the velocity of the fluid considered both in magnitude and direction, produced by the forces, cannot be calculated because the resulting velocity, wholly in magnitude and partly in direction, depends upon influences which act to restrain the flow, such as frictional resistance, viscosity of fluid, density of fluid, etc.,—and these are unknown.

It is easy to see, however, that the forces which produce a motor-effect are greatest at, or very close to, the apex of an angle, and consequently we can assume safely that the motor-effect is here quite considerable. The forces to produce the motor-effect diminish as the bath is approached, at which place these forces are practically nil.

Since it has never been shown, experimentally, heretofore, that a motor-effect can be produced separate from and uninfluenced by any internal pressure-effect, apparatus was made by me and an experiment was performed with this apparatus which *conclusively* demonstrated that a motor-effect can be produced apart from any internal pressure-effect. The experiment was made, but is not further referred to here.

SECTION V

EFFECT OF THE MUTUAL ATTRACTIONS OF CURRENT-ELEMENTS IN PRODUCING FLUID-MOTION.

Because of the mutual attractions of the current-elements in the conductor, the electrodynamic forces act toward the axis in the case of a conductor of circular cross-section, and, for the most part, normal to a median plane parallel to the length of the conductor, in the case of a conductor having the form of a narrow strip. These electrodynamic forces, pressing the fluid toward an axis or a plane, give rise, in virtue of Pascal's Law (that " Pressure exerted anywhere upon a mass of liquid is transmitted undiminished in all directions, and acts with the same force on all equal surfaces and in a direction at right angles to those surfaces,"

—*Ganot's Physics,* art. 97), to hydrodynamical forces which act to urge the fluid, near the axis or median plane of the conductor, in a direction parallel to the length of the conductor. If the conductor increases in cross-section suddenly, as it does in our case where it enters the bath, the longitudinal hydrodynamic forces are unbalanced by any opposing force, and consequently the fluid near the centre of the conductor is urged in the direction of the expanded portion of the conductor. As the fluid, however, is held in a rigid casing, there is developed a return current of fluid which flows near and parallel to the walls of the casing. We shall call the hydrodynamical forces which arise from the action of the mutual-attraction of current-elements in the single conductor, the *Internal Pressure Forces,* and we shall call any motion of the fluid which results from the action of these forces, the *Internal Pressure-effect.* This latter has long been known as the " Pinch Effect " (which, if carefully considered, is a misnomer).

The internal pressure forces act throughout the length of a conductor and are directly proportional to the mean square of the total current carried by the conductor, whether this be alternating or direct, and are inversely proportional to the cross-section of the conductor. As a consequence of the fact that in the " Wyatt furnace " the conductor opens out suddenly into a metal pool or bath, the internal pressure-effect is very marked at this place, because here the internal pressure forces are unbalanced by oppositely-directed forces. *The motor-effect, on the contrary, is far more marked near the apex of the V-shaped conductor.*

As a consequence, we reach the important conclusion: that *the Wyatt furnace has the peculiar and very practically desirable feature of developing hydrodynamical forces of considerable magnitude,* which give rise to fluid motions particularly at three points: the apex of the V-shaped conductor, and the two points where this V-shaped conductor enters the pool or bath of molten metal. Furthermore, the upright position occupied by the furnace effectually prevents any rupture of the circuit by the internal pressure-forces, and, in addition, offers the best disposition for any circulation of fluid which might arise from the tendency of the more highly-heated and less-dense fluid to rise.

It should be noted in conclusion that both the motor-effect and the internal pressure-effect increase with the square of the

current, and thus any increase in current will cause these two effects to increase in the same ratio. In the Wyatt furnace, I estimate the internal pressure-force approximately 1.3 times the maximum hydrodynamical force which gives rise to the motor-effect. It is reasonable to suppose that the two effects are in approximately the same ratio as the two forces which produce these effects.

SUMMARY AND CONCLUSIONS.

Section I.—A formula (page 821) is developed for calculating the mechanical forces which arise by the interaction of a triangular circuit carrying a current upon any short section of the circuit. Numerical results are tabulated (page 822) and values of the forces are given in a chart.

Section II.—Formulas are developed (page 823) for calculating the internal pressure-forces in a thin strip conductor. Numerical results are tabulated (page 824). A curve giving the pressure as a function of the distance from the axis of the strip is appended.

Section III.—The assumptions made in deriving Eq. (15), Section I, are considered; also the assumptions made for deducing Eq. (6), Section II.

Section IV.—The exact meaning and a definition of the *motor-effect* is given. It is shown also that such an effect actually exists and assumes considerable importance in the " Ajax-Wyatt furnace." A chart (Fig. 4) is given which shows the magnitude of the forces which produce the motor-effect. A new experiment is referred to which conclusively proved that the motor-effect not only exists, but may be manifested apart from, and independent of, any internal pressure-effect. The effect of the mutual attractions of current-elements in producing fluid motion are generally considered, and the *internal pressure-effect* is defined.

The important conclusion is reached that the Ajax-Wyatt furnace secures both the *internal pressure-effect* and the *motor-effect* in an advantageous way for obtaining practical results. It is further pointed out that the securing of these two effects at widely-separated sections of the conductor is a valuable and, as far as the writer knows, a novel result in furnace construction of the induction type.

THE ANNEALING OF GLASS.[*][†]

BY

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THE PROPER PROCEDURE FOR ANNEALING GLASS.

In considering the annealing of glass from a practical point of view, we must take account of three factors: (1) The kind of glass; (2) the initial amount of strain; and (3) the lower limit of strain, that is, the permissible amount of strain in the annealed glass. The rate of annealing, of course, depends on the chemical composition of the glass and also on the amount of strain. Furthermore, since the strain never actually disappears, but approaches zero asymptotically, the "time of disappearance" of strain at a given temperature will depend on the accuracy with which the strain can be measured; in other words, the annealing-time for a given temperature, or conversely, the annealing-temperature for a given time, will vary with the sensitivity of the strain-detector or with the amount of strain to be tolerated in the finished product.

Standard of Annealing.—The allowable strain will depend on the purpose for which the glass is to be used. Naturally, commercial glassware would require less complete removal of strain than lenses and prisms for optical instruments, but unfortunately little or no information is available for determining exactly the amount of strain which would be detrimental in the various kinds of glass articles. Twyman [44] proposes to call glass annealed when its internal stress has been reduced to 1/20 of the breaking stress and arbitrarily defines the annealing temperature as the temperature at which the given glass would lose in 3 minutes 95 per cent. of its original stress. The time required for the release of a given fraction of the stress is not, as Twyman apparently believed, independent of the initial stress, but nevertheless, Twyman's definition of "annealed" glass and of "annealing

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[*] Communicated by Dr. Arthur L. Day, Director of Laboratory.
[†] Concluded from page 631, Vol. 190, November, 1920.
[44] *Loc. cit.,* p. 70.

835

temperature " may furnish the basis for a convenient standard for manufactured articles of ordinary glass.

For optical glass F. E. Wright proposed as an arbitrary standard that the maximum path difference in an annealed block of glass shall not exceed $20\mu\mu$ per cm., basing this standard on the fact that the path difference per cm. in various samples of glass from Schott, Mantois, and Bausch and Lomb, examined by him, varied between 5 and $50\mu\mu$. During the war the standard of $20\mu\mu$ per cm. was adopted in the inspection of optical glass, and, in the absence of any definite knowledge of the amount of stress which causes warping of lenses and prisms with consequent impairment of the optical definition, some such arbitrary standard is necessary. Since it is a relatively simple matter to anneal glass so that the strain is much less than $20\mu\mu$ per cm., it is believed by the authors that the standard of good annealing might well be placed at a still lower value, say $10\mu\mu$ per cm. maximum path difference.[45] In a slab of glass viewed lengthwise the maximum path difference is at the two surfaces, and is usually about double the path difference along the middle. For slabs of glass (the form in which optical glass is usually supplied) the proposed standard of good annealing would limit the path difference along the *middle* to $5\mu\mu$ per cm. Since the release of stress proceeds according to equation (7), it follows that the annealing time is influenced more by the lower than by the upper limit of its stress. Thus, the time required to reduce the path difference from 100 to 5 is only 8 per cent. longer than the time to reduce the stress from 50 to 5, while on the other hand, the necessary time for changing the stress from 50 to 10 is less than 45 per cent. as long. Since unannealed optical glass is seldom strained to an extent corresponding [46] to more than $50\mu\mu$ per cm. (in the middle), it

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[45] In a private communication to the authors, Dr. Wright states that the standard of $20\mu\mu$ per cm. was placed at that value partly because under the stress of war conditions a fairly high limit was necessary. He also states that although glass with $20\mu\mu$ of strain will make satisfactory optical instruments, his own experience has demonstrated that it is quite feasible to anneal glass so that the strain is much less than $20\mu\mu$, and that, in agreement with us, he would place the standard of annealing for optical glass below the original value.

[46] A slab 2 cm. thick of any ordinary glass will show a path difference of $50\mu\mu$ per cm. along the middle when cooled at the rate of about 230° C. per hour. In a preliminary note (*J. Opt. Soc. Amer.*, **4**, 213–223, 1920), the authors defined annealing time on the basis of limits which were $50\mu\mu$ and $5\mu\mu$.

is convenient, when dealing with *optical* glass, to define the *annealing time* at a given temperature as the time required for the path difference (as determined by observation at the centres of the polished ends) to change from 50$\mu\mu$ to the chosen lower limit, which it might seem should be 5$\mu\mu$, our arbitrary standard. In what follows, however, it will be shown that the best method for the annealing of optical glass in actual practice requires the stress to be reduced (at the annealing temperature) to 2.5$\mu\mu$ per cm., if the final amount in the cold glass is to be 5$\mu\mu$. In connection with the annealing of *optical* glass, therefore, we define the *annealing time* at a given temperature as the time required to reduce the stress from 50 to 2.5$\mu\mu$. Thus, for ordinary crown the annealing time at 573° is 2 minutes, and for light flint the annealing time at 395° is 5 hours (see Table V). The *annealing temperature* for a given annealing time is similarly defined.

Annealing Range.—One other commonly used term needs to be mentioned in this connection. The range of temperature in which annealing ordinarily occurs is sometimes called the annealing-range of the glass in question. This is necessarily a rather loose term, since glass anneals at any temperature. Just as a substance such as mercury has no real " volatilizing range " but has a finite vapor pressure at all temperatures (except, of course, above the very high critical temperature, liquid-vapor), so glass anneals at a finite rate at all temperatures; and just as the lower limit of the " volatilizing range " would depend on the precision of the apparatus for measuring vapor-pressure, so the lower limit of the annealing range would depend on the delicacy of the method used for detecting strain. Nevertheless, there is a certain range of temperature in which most of the important operations connected with glass-annealing are conducted and in which the release of stress proceeds at an easily measured rate. This range extends over about 150° and is limited at the upper end by the temperature at which strain as ordinarily measured is seen to disappear when the heating rate is the usual amount of a few degrees per minute. Solely for convenience in referring to temperatures in this region, we shall therefore arbitrarily define the *annealing range* of a particular glass as that 150° interval of temperature lying immediately below the temperature at which the annealing time is 2 minutes. For example, as may be seen from Table V, the " annealing range " of ordinary crown glass is 423 to 573°.

The Necessary Conditions for Annealing.—In removing the strain from unannealed glass two problems are presented: First, the removal of the internal stress, and second, the prevention of its return. The removal of the stress is a simple process merely involving the heating of the glass to a sufficiently high temperature; to prevent the return of stress on cooling, however, is a much more complicated matter. As has already been explained, the permanent stress acquired by a piece of glass when cooled is equal and opposite in sign to the temporary stress lost by viscous yielding when the glass is in the " annealing range " of temperature. In other words, if a certain part of a glass block shows a birefringence corresponding to a *thrust* of 10 kg/cm.^{2}, then while the glass was hot the *tension* in that part of the block must have been reduced by 10 kg/cm.^{2} It is evident, therefore, paradoxical as it may seem, that in order to obtain the glass as free as possible from internal stress, it is necessary, while the glass is being cooled, to prevent the release of stress. The most obvious way in which to accomplish this is to reduce the amount of temporary stress, for, other things being equal, the less the stress the less will be lost. Hence the glass, after being maintained for a short time at the upper end of the annealing range, is cooled slowly so that the temporary stress introduced is comparatively small in amount; in fact, so small that even if it is all lost in cooling the final permanent strain will be within the allowable amount. This leads us to the:

Older Method for Annealing.—This method consists in heating the glass at a moderate rate to a temperature near the upper end of the annealing range. When the strain is judged to have disappeared, the heating is stopped, and the glass is then cooled slowly down to room temperature. For this method, the " annealing temperatures," that is, the maximum temperatures reached, need not be greater than those given in the fourth column of Table V. The permanent strain acquired by the glass will depend on the rate of cooling which for this method will necessarily be rather slow.

Improved Method for Annealing.—If instead of heating the glass to a relatively high temperature, we may hold it for a sufficient time at a temperature at which it takes several hours to anneal, we may then cool it fairly rapidly without causing the reappearance of permanent strain. The reason for this is as fol-

lows: The glass starts to cool, thus acquiring temporary strain, at a temperature at which the viscosity is high. Hence, although the temporary strain may be large, the amount lost during cooling will be comparatively small, and according to the theorem enunciated above, the permanent strain, being equal to the temporary strain lost in cooling, will also be small.

Thus, in contrast with the ordinary procedure of annealing glass for a short time at a high temperature, we may anneal it at a much lower temperature for a longer time; and, whereas, by the first method the subsequent cooling must be slow, by the second method it may be comparatively rapid.

This second method was used by the authors in annealing optical glass (over a hundred thousand pounds) at the Charleroi plant of the Pittsburgh Plate Glass Company, and the satisfactory results obtained indicated that this procedure possesses many advantages over the ordinary method. In the first place, it is much easier to hold an annealing kiln at a constant temperature than to cool it at a given constant rate. The newer method requires a fairly constant temperature for some hours, but the subsequent cooling takes place in a short time and does not need careful control, so that on the whole the chances of failure, particularly when unskilled workmen are employed to regulate the burners, are less than with the older method which involves the difficult operation of cooling at a constant slow rate. Another advantage of annealing at the lower temperature is that it minimizes the danger of overheating the glass. This is of especial importance when annealing valuable optical glass, large batches of which in several cases known to the authors have been spoiled, due to the fact that the temperature in the annealing furnace was accidentally allowed to become about 50° too high. Moreover, annealing at a low temperature not only saves time in heating up the glass to the annealing point, but also shortens somewhat the time of the actual annealing plus cooling, especially, as will be shown below, for larger blocks of glass. Finally, the danger of devitrification is obviously much less when the glass is annealed at a low temperature.

In this connection it may be mentioned that the procedure, sometimes followed, of heating glass to the upper end of the annealing range and then allowing it to " soak " at this temperature for several hours or over night, has no relation to the method

here advocated. When the glass has once been heated to the temperature at which it anneals almost instantly, nothing whatever is gained by holding it at the high temperature, and on the other hand, many of the disadvantageous features of the high-temperature method are correspondingly aggravated.

Rate of Cooling and Its Dependence on the Method of Annealing.—It follows from what has been said that there is a certain latitude allowable in the temperature at which glass may be annealed, and that the rate of cooling will be dependent on this temperature. The glass may be heated to its softening point and cooled at a rate which will cause the stress to be no more than the allowable amount, say, $5\mu\mu$, or, on the other hand, the temperature may be raised only to the point where the original stresses require some hours to be released, after which the temperature is allowed to fall rapidly. It is of interest to compare the relative time consumed by these two methods in order to determine whether or not by the second method the rate of cooling can be great enough to compensate for the much longer time spent at the annealing temperature. The problem of calculating the proper rate of cooling is a complicated one, and rather than attempt its complete solution we shall consider several special cases. Arbitrarily dividing the problem into two parts: (I) the case of glass heated to a temperature near (or above) the upper end of the annealing range, and (II) the case of glass annealed at a much lower temperature, we shall calculate for a slab of glass 2 cm. thick the strain introduced by cooling in certain specified ways.

(I) In this case the glass is heated to a temperature at which the annealing constant A is about 0.19. The annealing temperatures for the various glasses may therefore be taken from the fourth column of Table V. Temperatures higher than these are quite unnecessary, since with any ordinary heating rate the strain will have (sensibly) disappeared by the time this temperature has been reached. Supposing now that the strain has been removed from the glass, we shall proceed to calculate the strain introduced (a) by cooling at a constant rate, and (b) by cooling at a rate which increases in geometrical ratio.

(a) When glass is heated to a relatively high temperature and then cooled at a constant rate, the final stress is exactly the same as the *temporary* stress which would be caused by *heating* at the same rate. The stress in the middle for an average glass is there-

fore (see equation 54a below) $F = 4.6\ ha^2$, and the birefringence is

$$\triangle n = 4.6\ Bha^2 = ch \tag{10}$$

in which a is the semi-thickness, h is the cooling rate and c is the equivalent of $4.6\ Ba^2$, and is thus a constant depending on the properties of the glass and the dimensions of the block. The values of B for the more common optical glasses do not differ much from 2.8×10^{-7}. Hence for a slab 2 cm. thick c is about 13 if $\triangle n$ be measured in $\mu\mu$ per cm. and h be in deg. C. per minute. We are now able to calculate the allowable cooling rate for glass annealed by this method. Thus if the standard of annealing be taken as $5\mu\mu$ per cm. in the middle ($10\mu\mu$ at the surface), the allowable cooling rate from equation (10) would be $\frac{5}{13} = 0.385$ deg. per min. or 23 deg. per hr. Thus slabs of ordinary thickness when annealed by this method should be cooled at the rate of 23 deg. C. per hr. This rate varies somewhat with different kinds of glass, but except for the very heavy flints the divergence is not great. Furthermore, the rate of cooling is inversely proportional to the square of the thickness. Thus a lens blank 20 cm. thick would be cooled at a rate of $\frac{4}{400} \times 23 = 0.23$ deg. per hr., or 5.5 deg. per day, if not more than $5\mu\mu$ (in the middle) could be tolerated. With a limit of $25\mu\mu$ in the middle—50 at the surface—the corresponding rate by this method would be 27.5 deg. per day.

As a check on this calculation of the strain introduced by cooling at a given constant rate, the following experiment was performed: A slab of ordinary crown glass 2.2 cm. thick and 7.6 cm. long was heated in an electric furnace to a temperature considerably above the annealing range and cooled at a rate which, within the annealing range, was approximately constant and equal to about 4.3 deg. per min. When cold the glass was examined and the optical path difference along the middle found to be $415\mu\mu$, or $415/7.6 = 55\mu\mu$ per cm. According to equation (10) the birefringence should have been $4.6\ Bha^2$, or (since B for ordinary crown glass is 2.57), $4.6 \times 2.57 \times 4.3 \times (2.2/2)^2 = 61\mu\mu$ per cm. The agreement is satisfactory when the difficulty of maintaining an accurately constant cooling-rate is taken into consideration.

It has generally been recognized that in cooling glass it is not necessary to continue the constant cooling-rate right down to

room-temperature and that the rate can therefore be increased somewhat in the later stages of cooling. As will be shown later, comparatively little strain can be introduced below what we have called the annealing range, and hence the cooling-rate below the annealing range is limited mainly by what the glass will stand without breaking and by the rapidity with which it is practicable to cool the furnace. The tensile strength of glass is usually about 600 kg/cm.^{2}, which corresponds (cf. equation 54b) to a cooling rate equal to $\frac{65}{a^2}$ deg. per min. For safety a much lower maximum rate would be chosen—say, $\frac{10}{a^2}$ deg. per min. Finally, then, to anneal by this method a 2 cm. slab (a = 1) of borosilicate glass, it would be heated to 599°, cooled at a rate of 23 deg. per hr. for 150°, and then at a rate which may be as high as 10 deg. per min. until room temperature is reached. The time consumed (exclusive of that required for heating and for the latter, very rapid, cooling) would be 6.5 hours.

(b) For the case of cooling at a rate which increases in geometrical ratio, we proceed as follows : At any moment the temporary stress,[47] $(\triangle n)_t$ is equal to that due to the momentary cooling rate less that which has already disappeared by viscous release; that is,

$$(\triangle n)_t = ch - \triangle n$$

Moreover, from equation (7c),

$$-\frac{d(\triangle n)_t}{dt} = A (\triangle n)_t^2$$

But, as already stated, the final permanent stress is equal and opposite in sign to the temporary stress which has been lost. Hence

$$\frac{d(\triangle n)}{dt} = -\frac{d(\triangle n)_t}{dt} = A(\triangle n)_t^2 = A(ch - \triangle n)^2 \qquad (11)$$

and since

$$\frac{d(\triangle n)}{dt} = \frac{d(\triangle n)}{d\theta} \cdot \frac{d\theta}{dt} = -h\frac{d(\triangle n)}{d\theta}$$

we have

$$-\frac{d(\triangle n)}{d\theta} = \frac{A}{h}(ch - \triangle n)^2 \qquad (12)$$

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[47] For the sake of convenience, we use optical rather than mechanical units for the stress; i.e., in the present instance we consider $\triangle n$ rather than F.

as an expression for the permanent stress acquired by the glass.[48] Both A and h are functions of θ. Equation (8) may be written

$$A = A_0\, 2^{-\frac{\theta_0 - \theta}{p}}$$

which expresses the fact that A doubles for every p degrees increase in θ. Obviously $p = \frac{.301}{M_1}$ (see equation 8 and Table V) and is ordinarily about $10°$ C. For an average glass we may therefore write

$$A = A_0 2^{-\frac{\theta_0 - \theta}{10}}$$

Now, the cooling rate, h, is assumed to vary so that it doubles for every q degrees fall in temperature, or

$$h = h_0 2^{-\frac{\theta_0 - \theta}{q}}$$

If the interval q is taken as $20°$, equation (12) becomes

$$-\frac{d(\triangle n)}{d\theta} = \frac{A_0}{h_0} \left\{ ch_0 - (\triangle n)\, 2^{-\frac{\theta_0 - \theta}{20}} \right\} 2^{-\frac{\theta_0 - \theta}{20}} \tag{12a}$$

This equation can be conveniently integrated by graphical methods.[49] As an example, if the glass be annealed at a temperature given, for each kind of glass, in the fourth column of Table V, $A_0 = 0.19$; and if the initial cooling rate be taken as 6.0 deg. per hr., $h_0 = \frac{6.0}{60} = 0.10$. Moreover, for a slab 2 cm. thick $c = 13$. Substituting these values of A_0, h_0 and c in equation (12a) we have

$$-\frac{d(\triangle n)}{d\theta} = \frac{d(\triangle n)}{d(\theta_0 - \theta)} = 1.9 \left\{ 1.30 - (\triangle n)\cdot 2^{-\frac{\theta_0 - \theta}{20}} \right\}^2 2^{-\frac{\theta_0 - \theta}{20}} \tag{12b}$$

Figure 13 shows the curve obtained by the graphical solution of equation (12b). In this diagram the ordinates indicate the strain in $\mu\mu$ (in the middle) and the abscissæ the number of degrees through which the glass has cooled. It is to be noted that below $150°$ from the starting-point—that is to say, below what we have called the "annealing range"—very little additional strain

[48] It is to be noted that we neglect the fact that the glass is not uniform in temperature—an assumption which (at least for pieces of ordinary size) will not introduce any serious error.

[49] See Carl Runge: "Graphical Methods." New York, 1912, p. 120, et seq.

is introduced. As shown by the figure, the final strain in this case is about $10.7\mu\mu$ per cm.

The time required for cooling is obviously

$$t_c = -\int_{\theta_0}^{\theta} \frac{d\theta}{h} = -\frac{1}{h_0}\int_{\theta_0}^{\theta} 2^{-\frac{\theta_0-\theta}{20}}\,d\theta$$

if h doubles every $20°$, and even if as above we make the limiting rate 10 deg. per min. (for $a=1$), it can be shown that the total

Fig. 13.
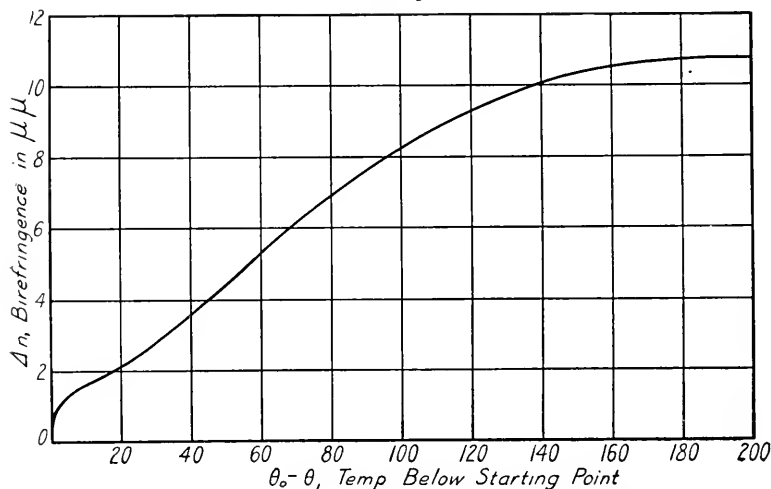
Graphical solution of equation (12b). The abscissæ represent the number of degrees through which the glass has cooled, and the ordinates represent birefringence in $\mu\mu$.

cooling-time is approximately equal to the above integral, which if θ and θ_0 differ by $100°$ or more, is approximately

$$t_c = \frac{29}{h_0} \qquad (13)$$

In the example given we have taken h_0 equal to 6.0 deg. per hr. which equals 0.10 deg. per min. Hence the cooling time is approximately $\frac{29}{0.10} = 290$ minutes, when $10.7\mu\mu$ of strain is incurred. Now it so happens that for small values of h_0, the strain introduced is nearly proportional to h_0 and hence inversely proportional to t_c. If only $5\mu\mu$ is to be incurred the initial cooling rate would be $\frac{5}{10.7}\times$ $6.0 = 2.8$ deg. per hr. and the cooling time would be $\frac{10.7}{5}\times 290 =$

620 minutes, or over 10 hours. Comparing this value with the cor-responding one for method Ia (linear cooling), we have 10 hours as against 7 hours. It is evident, therefore, that when glass is annealed in the customary manner—that is, at a comparatively high temperature—nothing is gained by increasing the cooling rate so fast that at the *beginning* it doubles for every 20° drop in temperature. Furthermore, the higher the temperature the more disadvantageous it is to increase the cooling-rate rapidly at the start.

(II) When glass is annealed from a relatively low tempera-ture the annealing time is large enough to be taken account of and can not be neglected as when the annealing is carried out at a high temperature. Furthermore, for the sake of generality it is neces-sary to consider that the glass is not *completely* annealed (as in the preceding examples) at the high temperature, but that at this temperature the stress is reduced to a certain amount $(\Delta n)_a$, the difference between this and the permissible amount being incurred during the cooling process. If $5\mu\mu$ per cm. be taken as the per-missible final strain, then $5 - (\Delta n)_a$ is introduced during cooling. At relatively low temperatures the temporary stress (equal to ch') will ordinarily be much greater than the final permanent stress. In equation (11), therefore, Δn, being small in comparison with ch', may be neglected on the right-hand side of the equation and we have for the strain introduced by cooling:

$$\frac{d(\triangle n)}{dt} = A c^2 h'^2 \tag{14}$$

Similarly equation (12) becomes

$$-\frac{d(\triangle n)}{d\theta} = A c^2 h' \tag{15}$$

or since $A = A_{o2} - \frac{\theta_o - \theta}{10}$

$$-\frac{d(\triangle n)}{d\theta} = A_o c^2 h' 2^{-\frac{\theta_o - \theta}{10}} \tag{16}$$

(*a*) *Cooling at constant rate.* As in case (I, a), let us assume that the glass is cooled at a constant rate, h', down to the lower end of the annealing range, and thereafter at a very high

rate equal to $\frac{10}{a^2}$ deg. C. per min. From (16) the strain intro-
duced by cooling from θ_0 to θ is

$$c^2 A_0 h' \int_{\theta_0}^{\theta} 2^{-\frac{\theta_0 - \theta}{10}} d\theta.$$

The value of the integral, if $\theta_0 - \theta$ is at least a large fraction of
$100°$, is approximately $10/\ln 2 = 14.5$. Then, the strain to be
acquired during cooling is

$$(\triangle n)_c = 5 - (\triangle n)_a = 14.5\, c^2 A_0 h' \qquad (17')$$

To find the cooling time we assume that the constant cooling ex-
tends over a range [50] of $90°$. The cooling time, t_c (exclusive of
the time for the final very rapid cooling) is therefore

$$t_c = \frac{90}{h'} \qquad (18')$$

and substituting the value of h' from $(17')$ we have

$$t_c = \frac{90 \times 14.5\, c^2 A_0}{5 - (\triangle n)_a} \qquad (19')$$

Moreover, from equation $(7c)$ the annealing time is

$$t_a = \frac{\dfrac{1}{(\triangle n)_a} - \dfrac{1}{50}}{A_0} \qquad (20)$$

From these expressions for t_c and t_a it is important to find the
relation between A_0, the annealing constant (and thence the
annealing temperature), $(\triangle n)_a$, the degree of initial annealing,
and h_0, the subsequent cooling rate, so that the total time required
for the annealing process shall be a minimum. This total time is

$$t_a + t_c = \frac{\dfrac{1}{(\triangle n_a)} - \dfrac{1}{50}}{A_0} + \frac{90 \times 14.5\, c^2 A_0}{5 - (\triangle n)_a}$$

By partial differentiation with respect to A_0 and with respect to
$(\triangle n)_a$ it is found that the total time is a minimum when

$$t_a = t_c \qquad (21)$$

and

$$(\triangle n)_a = 2.57 \qquad (22)$$

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[50] The justification for this assumption will be apparent from what
follows. In any case, the proper range can be found by trial and approxi-
mation, and moreover, a considerable variation in the assumed range will
not vitiate the deductions which follow.

It is also found that

$$A_o = \frac{0.95}{c\sqrt{90 \times 14.5}} \qquad (23')$$

and

$$h_o' = \frac{90}{0.37} A_o = \frac{6.4}{c} \qquad (24')$$

Now, the validity of these relations depends on the assumption that at any moment the stresses are proportional to the rate of cooling. It is to be noted, however, that when the glass, after being annealed until the stress is $(\Delta n)_a$, is cooled at a certain rate, the first part of the cooling rate merely neutralizes the stress already present. The rate necessary to neutralize the stress $(\Delta n)_a$ is $\frac{(\Delta n)_a}{c}$, and hence at any moment the actual stress is equal to $c(h - \frac{(\Delta n)_a}{c})$. The above equations are therefore more nearly correct if h' is not the total cooling rate, but is the rate in excess of that required to neutralize the residual stress. If then h is the true cooling rate

$$h = h' + \frac{(\Delta n)_a}{c}$$

The correct relations may be obtained by revising the preceding equation, taking proper account of the difference between h and h'. Making the appropriate changes [51] in the equations, we find that h should be equal to $1.4\ h'$ and that as before, for minimum time

$$(\Delta n)_a = 2.57 \qquad (22)$$

The equation for the strain incurred by the cooling becomes

$$(\Delta n)_c = 5 - (\Delta n)_a = 10 \times c^2 A_o (h - \frac{(\Delta n)_a}{c}) \qquad (17)$$

The equation for the cooling time may now be written

$$t_c = \frac{90}{h} \qquad (18)$$

or

$$t_c = \frac{64 \times 10\ c^2 A_a}{5 - (\Delta n)_a} = 264\ c^2 A_o \qquad (19)$$

[51] It will be noted that the change made is in some cases a correction and in others a substitution.

while on the other hand, the equation for the annealing time remains the same :

$$t_a = \frac{\frac{1}{(\triangle n)_a} - \frac{1}{50}}{A_o} = \frac{0.37}{A_o} \qquad (20)$$

The correct value for the annealing constant is now

$$A_o = \frac{0.95 \times 1.4}{c \sqrt{90 \times 14.5}} = \frac{0.037}{c} \qquad (23)$$

and the subsequent cooling rate is

$$h = \frac{6.4 \times 1.4}{c} = \frac{9.0}{c} \qquad (24)$$

Finally, then, if glass is to be annealed at a comparatively low temperature, with subsequent cooling at a constant rate, the total time required, that is, the sum of the annealing time and the cooling time, will be least when the glass is annealed down to one-half the allowable strain by holding at a temperature at which $A_o = 0.037/c$, and then cooling at constant rate equal to $9.0/c$. deg. per min. The constant rate is continued down to the lower end of the "annealing range," after which it may be cooled at the much greater rate, $\frac{10}{a^2}$. As an example : for a plate of glass 2 cm. thick, $a = 1$, and hence $c = 13a^2 = 13$. Hence, by equation (23), $A_o = 0.037/13 = 0.00285$. For ordinary crown glass this corresponds to a temperature of $511°$ (see equation (8) and Table V). The cooling rate by equation (24) is $9.0/13 = 0.69$ deg. per min. $= 41$ deg. per hr. The cooling time will be approximately $\frac{90}{41} = 2.2$ hours and the total time required will be approximately twice this, or 4.4 hours.

(b) *Cooling at an increasing rate.* If we assume that at comparatively low temperatures the release of stress is represented by $-d(\triangle n)/d\theta = Ac^2h'$, it can be shown [52] that for the introduction

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[52] The cooling time between any two temperatures θ_1 and θ_2 is obviously $t_c = \int_{\theta_1}^{\theta_2} \frac{d\theta}{h}$, and the strain introduced is $(\triangle n)_c = c^2 \int_{\theta_1}^{\theta_2} Ah d\theta$. To find h as a function of θ so that t_c and $(\triangle n)_c$ will both have minimum values, we apply the methods of the calculus of variations (cf. B. Williamson: "Integral Calculus," 7th ed., p. 437), which show that for a slight variation in the function defining h, $c^2A = b/h^2$ where b is a constant. That is, $Ah^2 = \frac{b}{c^2} =$ constant.

of a given amount of strain in the cooling process, h' should be progressively increased so that it doubles for every $2p$ degrees drop in temperature. Since p is ordinarily about $10°$, h' should double for every $20°$. That is, $h' = h'_0\ 2^{\frac{\theta_0 - \theta}{20}}$ in which h'_0 is the value of h' at θ_0. Since Ah'^2 remains constant and equal to its initial value, equation (14) may be written

$$\frac{d(\triangle n)}{dt} = c^2Ah'^2 = c^2A_0h_0'^2 = constant. \tag{25}$$

Starting with this equation and proceeding, as in IIa, we find finally that $h = h' + \frac{(\triangle n)_a}{c} = h' + h_0'$, or $h_0 = 2h_0'$. Hence,

$$h_0 = \frac{h_0}{2}(1 + 2^{\frac{\theta_0 - \theta}{20}}) \tag{26}$$

which expresses the fact that the cooling rate is made up of two parts, one of which is constant while the other doubles for each $20°$ drop in temperature. It follows that the strain incurred during cooling is

$$(\triangle n)_c = 5 - (\triangle n)_a = \frac{c^2A_0h_0^2t_c}{4} \tag{27}$$

and the cooling time is approximately

$$t_c = \frac{40}{h_0} \tag{28}$$

or

$$t_c = \frac{20^2c^2A_0}{5 - (\triangle n)_a} \tag{29}$$

As before, the annealing time is

$$t_a = \frac{1}{\dfrac{(\triangle n)_a}{A_0}} - \frac{1}{50} \tag{30}$$

Hence h^2 is inversely proportional to A, or h^2 doubles when A is halved, and since A is halved for each p degrees drop in temperature, h doubles for each $2p$ degrees, or about $20°$. The validity of this proof is somewhat affected by the failure to distinguish between h, the true cooling rate, and h', the cooling rate in excess of that required to neutralize the residual strain $(\triangle n)_a$. Taking account of this fact, however, we find that the requirement for minimum cooling time is approximately that h', not h, doubles for every 20 degrees drop in temperature.

and for minimum total time $t_a = t_c$ and $(\Delta n)_a = 2.57$. Hence the glass should be annealed at the temperature at which

$$A_0 = \frac{0.047}{c} \qquad (31)$$

and cooled at a rate which initially is

$$h_0 = \frac{5.2}{c} \qquad (32)$$

and which increases progressively according to equation (26).

For a slab of glass 2 cm. thick the value of c is about 13, and hence A_0 should be $0.047/13 = 0.0036$, which in the case of ordinary crown glass corresponds to a temperature of $514°$; that is, nearly $60°$ below the upper limit of the annealing range. The annealing time would be $0.37/0.0036 = 103$ minutes $= 1.7$ hours, and the total time [53] for annealing plus cooling would be twice this or 3.4 hours. The initial cooling rate by equation (32) would be $\frac{5.2}{13} \times 60 = 24°$ per hr. Both A_0 and h_0 are inversely proportional to c, which is proportional to the square of the thickness. Hence, the thicker the glass the lower the temperature at which it is annealed and the slower is the initial cooling.

The total time required by each of the four procedures considered follows: Ia, 6.5 hrs.; Ib, 10.3 hrs.; IIa, 4.4 hrs.; and IIb, 3.4 hrs. It appears, therefore, that the low-temperature annealing procedure (methods IIa and IIb) has in addition to the other advantages enumerated above, the advantage of requiring less time. This saving of time becomes more important as the size of the glass is increased.

ANNEALING SCHEDULES FOR VARIOUS KINDS OF GLASS.

Optical Glass.—On the basis of the preceding discussion it is possible to state with fair precision the best procedure for annealing glass of various kinds and of various sizes and shapes. Methods IIa and IIb are both satisfactory for optical glass. IIa (cooling at constant rate), as compared with IIb (cooling at increasing rate), requires a lower temperature but a slightly

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[53] Exclusive, as before, of the short time required for the latter, very rapid cooling.

longer total time. The constant rate, according to IIa, however, is larger than the initial rate, according to IIb, a fact which tends to make IIa the more advantageous; but the rate by method IIb is increased so rapidly that this advantage holds only for the first small portion of the cooling. On the whole, we believe that method IIb is the best for the practical annealing of optical glass. The procedure recommended is therefore briefly as follows: If the glass to be annealed is cold, it is heated rapidly [54] to a temperature at which A_0, as determined from equation (8) and Table V, is equal to $0.0047/c$. If the glass is hot, as, for example, after being pressed or molded, it is brought immediately into a kiln or furnace previously heated to the given temperature. The glass is held at this temperature for $0.37/A_0$ minutes, and is then cooled at a rate which initially is $5.2/c$ deg. C. per min., and which is gradually increased according to the relation $h = \dfrac{h_0}{2} (1 + 2^{\frac{\theta_0 - \theta}{20}})$ until the rate is $10/a^2$, after which the rate is, so far as is practicable, maintained constant. The value of c, as already explained, depends on the size and shape of the glass blocks, but varies comparatively little for various kinds of glass. Optical glass is usually supplied in the form of plates or slabs, for which the value of c is about $13a^2$, a being the semi-thickness. For other shapes the value of c can be estimated from equations (55) and (56). Since c is proportional to a^2, it is obvious that doubling the thickness decreases the annealing temperature by about $20°$, and increases the annealing time (and also the cooling time) to four times its original value.

In Table VII are given condensed annealing schedules for slabs of various thickness, as calculated from equations (30), (31), and (32), using the values of A obtained from equation (8) and Table V. To the annealing times for the corresponding annealing temperatures have been applied a factor of safety equal to 2, in order to compensate for possible errors in temperature measurement in the kilns or furnaces in which the annealing is to be done. Thus a slab 10 cm. thick should, according to the

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[54] The heating rate, if approximately uniform, may be much greater than the maximum cooling rate (see below). A heating rate of $\dfrac{20}{a^2}$ to $\dfrac{30}{a^2}$ deg. C. per min. is quite safe.

TABLE VII.

Annealing Schedule for Optical Glass Slabs of Varying Thickness, Assuming that Strain Along the Middle (When the Glass is Viewed Through the Edges) is Finally to be no More Than $5\mu\mu$ per cm.

(Hold the glass at the proper annealing temperature for the indicated time and cool at the indicated rate.)

Thickness	1 cm.	2 cm.	5 cm.	10 cm.	20 cm.
Kind of glass	Annealing temperatures, deg. C.				
Borosilicate crown	561	541	515	495	475
Ordinary crown	535	514	487	466	445
Light barium crown	571	552	527	508	489
Heavy barium crown	608	592	572	556	540
Barium flint	516	494	466	454	423
Light flint	427	408	384	366	348
Medium flint	434	418	397	382	366
Heavy flint	424	407	386	370	353
Extra heavy flint	400	382	357	339	321

	Annealing times				
	50 min.	$3\frac{1}{2}$ hrs.	21 hrs.	86 hrs.	14 days
	Cooling rates—degrees C. per hour				
Initial rate	96	24	3.8	1.0	0.2
Rate after 10°	116	29	4.6	1.2	.3
Rate after 20°	144	36	5.8	1.4	.4
Rate after 30°	184	46	7.4	1.8	.5
Rate after 40°	240	60	9.6	2.4	.6
Rate after 50°	319	80	13.	3.2	.8
Rate after 60°	432	108	17.	4.3	1.1
Rate after 70°	591	148	24.	5.9	1.5
Rate after 80°	816	204	33.	8.2	2.0
Rate after 90°	1134	283	55.	11.	2.8
Rate after 100°	1584	396	63.	16.	4.0
Maximum cooling rate	2400	600	96.	24.	6.
Maximum heating rate	7200	1800	288.	72.	18.

formulæ, be annealed at the proper temperature for 43 hours, but the table gives twice this value, or 86 hours. That this factor of safety is unnecessary if the temperature is known to within a degree or two is proved by the following experiment: A slab of borosilicate crown glass 2 cm. thick and 7.6 cm. long, which showed when viewed lengthwise a strain (along the middle) corresponding to $850\mu\mu$; that is, $850/7.6 = 112\mu\mu$ per cm., was subjected to the thermal treatment indicated in Table VIII. The furnace was the same in which the previously described measurements were made. The total time from the moment the cold

TABLE VIII.

Record of the Actual Annealing of a Slab of Borosilicate Glass 7.6 cm. long and 2 cm. thick. Original Stress along Middle, 850μμ, or 112μμ per cm. Total Time, 4 hr. 50 min. Strain after Annealing, 46μμ, or 6μμ per cm.

Time	Temp. °C.	Remarks
9 : 45 A.M.	25	Glass put in cold furnace.
: 56 A.M.	179	
10 : 08 A.M.	337	Temporary strain about 2000μμ.
: 25 A.M.	496	
: 31 A.M.	539	
: 33 A.M.	543.3	Temperature held approximately constant.
: 35 A.M.	542.1	
: 40 A.M.	541.6	
: 43 A.M.	541.8	
: 44 A.M.	542.0	
12 : 18 P.M.	542.8	Cooling started.
: 20 P.M.	. . . .	Cooling rate 0.37 deg./min.
: 26 P.M.	540.7	
: 28 P.M.	. . . .	Cooling rate 0.40 deg./min.
: 35 P.M.	. . . .	Cooling rate 0.48 deg./min.
: 38 P.M.	535.5	
: 39 P.M.	. . . .	Cooling rate 0.44 deg./min.
: 43 P.M.	. . . .	Cooling rate 0.58 deg./min.
: 50 P.M.	. . . .	Cooling rate 0.51 deg./min.
: 53 P.M.	527.7	
: 55 P.M.	. . . .	Cooling rate 0.54 deg./min.
1 : 06 P.M.	520.8	
: 08 P.M.	. . . .	Cooling rate 0.65 deg./min.
: 11 P.M.	. . . .	Cooling rate 0.71 deg./min.
: 17 P.M.	512.5	
: 20 P.M.	. . . .	Cooling rate 0.84 deg./min.
: 24 P.M.	. . . .	Cooling rate 0.88 deg./min.
: 28 P.M.	502.5	
: 30 P.M.	. . . .	Cooling rate 1.00 deg. /min.
: 34 P.M.	. . . .	Cooling rate 1.20 deg./min.
: 38 P.M.	490.3	
: 40 P.M.	. . . .	Cooling rate 1.35 deg./min.
: 41 P.M.	. . . .	Cooling rate 1.5 deg. min.
: 42 P.M.	. . . .	Cooling rate 1.7 deg./min.
: 44 P.M.	480.1	
: 46 P.M.	. . . .	Cooling rate 2.0 deg./min.
: 48 P.M.	. . . .	Cooling rate 2.2 deg./min.
: 49 P.M.	469.0	
: 51 P.M.	359.0	
: 52 P.M.	. . . .	Cooling rate 3.2 deg./min.
: 57 P.M.	439.0	
: 58 P.M.	. . . .	Door partly open.
2 : 00 P.M.	. . . .	Door fully open.
2 : 35 P.M.	. . . .	Glass taken out of furnace.

glass was put into the furnace until it was taken out,[55] was 4 hours and 50 minutes, and the final strain was 45μμ, or about

[55] The temperature of the *glass* at this moment was not measured, but was probably somewhat above 100°.

$6\mu\mu$ per cm., which—within little more than the error of experiment—was the expected amount.

In Fig. 14 the procedure now recommended for annealing optical glass is compared graphically with the hitherto customary method for the specific case of a slab of ordinary crown glass 2 cm. thick.

While the directions in Table VII are strictly applicable only when the glass is in the form of plates or slabs, and when the standard of annealing is put at $5\mu\mu$, the necessary modification of the schedules for the case of another shape or another standard

Fig. 14.
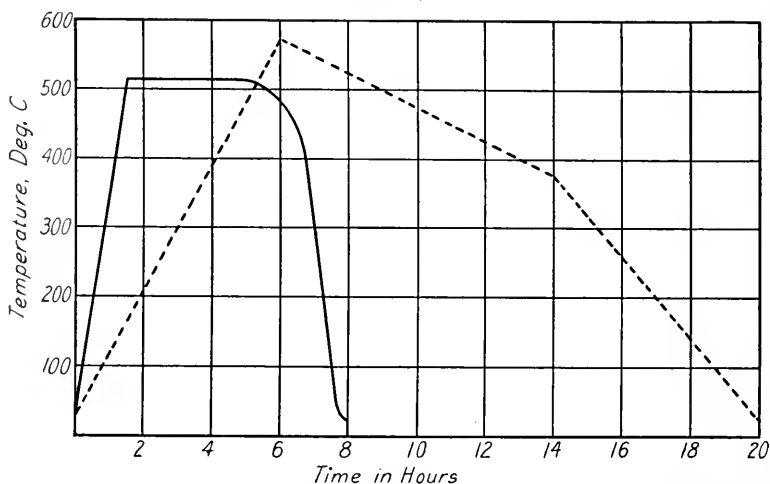
Graphical comparison of the annealing procedure now recommended (full line) and the procedure ordinarily followed (dotted line).

of annealing can be readily made. For example, if the value of c were doubled, A_o would be halved, the annealing temperature would be lowered about $10°$, and the annealing and cooling time would each be doubled. On the other hand, an increase in the allowable amount of strain would not affect the annealing temperature but would decrease both the annealing and the cooling time.

Plate Glass.—The procedure for plate glass will differ from that for optical glass mainly because the quality of annealing need not be so good. Indeed, the principal requirement for plate

glass is that after casting, it be somehow cooled down to room temperature without breaking.

It is interesting to note, moreover, that since a given amount of final permanent strain is a consequence of the release of the same amount of temporary reverse strain in the early stages of cooling, a plate of glass which is initially cooled so as to show permanent strain can be safely cooled at a correspondingly greater rate than a plate which finally shows no strain. In this respect, therefore, a certain amount of strain is an advantage, but on the other hand, an excess of strain, as explained below, would render the glass difficult to cut and would make it less resistant to sudden *rises* in temperature.

There seems to be no information available on which to estimate the limiting strain which could be allowed in plate glass. Ordinary plate glass, however, commonly shows 30$\mu\mu$ per cm. (along the middle when viewed longitudinally), and it is probably safe to assume that nothing would be gained by making the strain any less than that amount.

Twyman's [56] proposal that the internal stresses in commercial glassware should be limited to 1/20 of the heating stress would correspond to about 100$\mu\mu$ per cm. In the absence of more definite information on the subject, we may take 50$\mu\mu$ per cm. as the desirable upper limit of strain in plate glass.

The composition of plate glass is commonly about the same as that of the ordinary crown glass which we have used. In determining a suitable annealing schedule the annealing constants for ordinary crown glass may therefore be used. For the sake of simplicity we would choose method IIa (see above), and by making the appropriate changes in equations (17) to (24) so as to take account of the fact that the glass is to be annealed down to 25$\mu\mu$ per cm. by holding at a given temperature, and that the additional 25$\mu\mu$ strain is to be acquired during cooling, we arrive at the conclusion that plate glass should be annealed by holding at such a temperature that $A = \frac{0.037}{c}$, and then cooling at a constant rate equal to $\frac{80}{c}$ = for the first 100°. Thus for sheets 2 cm. thick ($c = 13$) the annealing process would be as follows: After being

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[56] *Loc. cit.*

cast, the glass would be brought to a temperature of about 511°, held at that temperature for 15 minutes, and then cooled at a constant rate equal to 6° C. per minute until the temperature had fallen 100°, after which (see above) the cooling rate may safely be as high as 10 or 20 degrees per minute. For thicker or thinner plates the annealing temperature would vary, and the annealing and cooling time would be correspondingly increased or decreased.

Other Kinds of Glass.—For the various other kinds of glass articles such as bottles, lamp-bulbs, cut-glass, chemical glassware, and so on, much that has been said in connection with the annealing of plate glass will apply. The problem is complicated, however, by the variety of compositions and of shapes which are encountered. In general, before an annealing schedule can be given for any one kind of glass, its annealing characteristics must be determined experimentally by measurements at two or more temperatures, but since the change with temperature of the annealing rate is roughly the same for all glasses and great precision is not necessary, a knowledge of the annealing rate at one temperature or of the " annealing temperature " for some specified set of conditions, will usually suffice. The " annealing temperatures " as given by English and Turner (see Table VI) for various glasses, afford useful information from which, by comparison with the results we have given, an approximately correct annealing procedure for many of the glasses can be deduced. As with plate glass, a limiting strain of $50\mu\mu$ per cm. is recommended, and the complication due to varied shapes may in many cases be circumvented by treating the article (*e.g.*, a bottle, or a beaker) as a slab of thickness equal to twice the maximum thickness of any part of the given article.

TEMPERATURE DISTRIBUTION AND STRESSES: OPTICAL PATH DIFFERENCES DUE TO THERMAL GRADIENTS.

Temperature Distribution During Heating and Cooling.—The first step in the estimation of the thermal stresses produced in glass is the calculation of the temperature gradients under the assumed conditions. Appropriate formulæ for two types of heating have already been given.[57]

[57] E. D. Williamson and L. H. Adams: *Phys. Rev.*, 14, 99-114 (1919).

For the case of the *sudden change of surface-temperature* the three most generally useful [58] formulæ are:

Slab

$$H = 2 \sum_{m=1}^{m=\infty} \left\{ \frac{1}{Q_m (-1)^{m+1}} e^{-\frac{\kappa Q^2_m t}{a^2}} \cos \left(\frac{Q_m x}{a} \right) \right\} \qquad (33)$$

Cylindrical rod

$$H = 2 \sum_{m=1}^{m=\infty} \left\{ \frac{1}{R_m J_1(R_m)} e^{-\frac{\kappa R^2_m t}{a^2}} J_0 \left(\frac{R_m x}{a} \right) \right\} \qquad (34)$$

Sphere

$$H = 2 \sum_{m=1}^{m=\infty} \left\{ \frac{1}{S_m (-1)^{m+1}} e^{-\frac{\kappa S^2_m t}{a^2}} \frac{a}{x} \sin \left(\frac{S_m x}{a} \right) \right\} \qquad (35)$$

where

$$H = \frac{\theta - \theta_f}{\theta_i - \theta_f}$$

θ is the temperature at any point; θ_i, the initial uniform temperature of the solid; θ_f, the constant temperature of the surface; κ, the thermal diffusivity (equal to the thermal conductivity divided by the product of the specific heat and the density); t, the time;

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[58] For points close to the surface or for small values of t the infinite series (33), (34), and (35) are not very rapidly convergent. Under these conditions the following formulæ are more convenient:

Sphere

$$1 - H = \frac{2a}{x\sqrt{\pi}} \left\{ \int_{q_0 - q}^{q_0 + q} e^{-s^2} ds + \int_{3q_0 - q}^{3q_0 + q} e^{-s^2} ds + \int_{5q_0 - q}^{5q_0 + q} e^{-s^2} ds + \ldots \right\}$$

Slab

$$1 - H = \frac{2}{\sqrt{\pi}} \left\{ \int_{q_0 - q}^{3q_0 + q} e^{-s^2} ds + \int_{q_0 + q}^{3q_0 - q} e^{-s^2} ds + \int_{5q_c - q}^{7q_0 + q} e^{-s^2} ds + \int_{5q_0 + q}^{7q_0 - q} e^{-s^2} ds + \ldots \right\}$$

or

$$H = \frac{2}{\sqrt{\pi}} \left\{ \int_0^{q_0 - q} e^{-s^2} ds - \int_{q_0 + q}^{3q_0 - q} e^{-s^2} ds + \int_{3q_0 + q}^{5q_0 - q} e^{-s^2} ds - \ldots \right\}$$

where s is an integration variable, $q = x/2 \sqrt{\kappa t}$, $q_0 = a/2 \sqrt{\kappa t}$ and H, a, x, K and t have the same meaning as above. *Cf.* R. S. Woodward: *Phys. Rev.*, **16**, 176, 177 (1903); and A. L. Queneau: *School of Mines Quart.*, **23**, 181–195 (1902).

a, one-half the diameter or thickness; x, the distance from the centre; J_0 (   ) and J_1 (   ) are Bessel's functions of the zeroth and first order; m is any integer; and Q_m, S_m, and R_m are written respectively for $(2m - 1)\pi/2$, $m\pi$, and the roots of the equation $J_0\ (x) = 0$.

For the case of *linear heating* of the surface, we have the corresponding equations:

Slab

$$\theta = ht - \frac{h}{2\kappa}(a^2 - x^2) + \frac{2ha^2}{\kappa}\sum_{m=1}^{m=\infty}\frac{1}{Q_m{}^3(-1)^{m+1}}\,e^{-\frac{\kappa Q_m{}^2 t}{a^2}}\cos Q_m\left(\frac{x}{a}\right). \quad (36)$$

Cylinder

$$\theta = ht - \frac{h}{4\kappa}(a^2 - x^2) + \frac{2ha^2}{\kappa}\sum_{m=1}^{m=\infty}\frac{1}{R_m{}^3 J_1(R_m)}\,e^{-\frac{\kappa R_m{}^2 t}{a^2}}\,J_0\left(R_m\frac{x}{a}\right). \quad (37)$$

Sphere

$$\theta = ht - \frac{h}{6\kappa}(a^2 - x^2) + \frac{2ha^2}{\kappa}\sum_{m=1}^{m=\infty}\frac{1}{S_m{}^3(-1)^{m+1}}\,e^{-\frac{\kappa S_m{}^2 t}{a^2}}\frac{a}{x}\sin\left(S_m\frac{x}{a}\right). \quad (38)$$

When t became large with respect to a, the last term of (36), (37), or (38) vanishes, and the temperature gradient reaches a " steady state " in which the temperature distribution is represented by a parabola. The equations for this steady state are:

Slab

$$\theta = ht - \frac{h}{2\kappa}(a^2 - x^2) \quad (39)$$

Cylinder

$$\theta = ht - \frac{h}{4\kappa}(a^2 - x^2) \quad (40)$$

Sphere

$$\theta = ht - \frac{h}{6\kappa}(a^2 - x^2) \quad (41)$$

Finally for *linear heating* of cylindrical tubes and spherical shells, if a_1 and a_2 are respectively the internal and external radii, we have the steady state equations.[59]

Cylindrical Tube.—(a) Heat transfer taking place only at outside,

$$\theta = ht - \frac{h}{4\kappa}\left(a_2{}^2 - x^2\right) + \frac{ha_1{}^2}{2\kappa}\ln\frac{a_2}{x} \quad (42a)$$

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[59] The general equations corresponding to (42a), (42b), and (43) can be obtained by the proper substitutions.

(*b*) Heat transfer taking place equally at inside and outside,

$$\theta = ht + \frac{hx^2}{4\kappa} + \frac{h\left(a_1{}^2 \log \frac{x}{a_2} - a_2{}^2 \log \frac{x}{a_1}\right)}{4\kappa \log \frac{a_2}{a_1}} \tag{42b}$$

Spherical Shell.—Heat transfer taking place only at outside,

$$\theta = ht + \frac{h(x^2 - a_2{}^2)}{6\kappa} + \frac{ha_1{}^3}{3\kappa}\left(\frac{1}{x} - \frac{1}{a_2}\right) \tag{43}$$

Stresses Due to Temperature Gradients.—These stresses may be evaluated from the following equations: [60] in which α is the coefficient of linear (thermal) expansion, $e = \frac{1}{3R} + \frac{1}{9K}, f = \frac{1}{6R} - \frac{1}{9K}$ and θ' is the difference between the temperature at any point and the temperature of the surface.

Slab

$$F = \frac{C_1 - \alpha\theta'}{e - f} \tag{44}$$

where

$$C_1 = \frac{a}{a} \int_0^a \theta' dx \tag{44a}$$

and F is the tension in any direction parallel to the faces of the slab.

Cylindrical Tube.—If the temperature distribution be symmetrical about the axis, F_a, F_r, and F_t, the axial, radial and tangential stresses, may be obtained from the three equations:

$$(e - f)F_a + \alpha\theta' = C_1 \tag{45a}$$

$$xF_r{}^2 = -\frac{a}{e - f}\int x\theta' dx + \frac{C_2 x^2}{2} + C_3 \tag{45b}$$

$$F_t = F_r + x\frac{dP_r}{dx} \tag{45c}$$

C_1, C_2 and C_3 being constants of integration which are evaluated from the boundary conditions. For a solid cylinder the same equations apply, except that C_3 is zero.

[60] *Cf.* Williamson: *loc. cit.*

Spherical Shell.[61]—With temperature distribution symmetrical about the centre, we have

$$x^3 F_r = -\frac{2a}{e-f} \int x^2 \theta^1 dx + C_1 \frac{x^3}{3} + C_2 \tag{46a}$$

$$F_t = F_{r_1}^{\prime} + \frac{x}{2} \frac{dF_r}{dx} \tag{46b}$$

C_1 and C_2 being integration constants. For a solid sphere C_2 vanishes.

The above equations may be used to determine the stresses in the various solids when the heating or cooling is carried out in a certain specified manner. As an example of their application, we may consider (A) linear heating of the surface, and (B) sudden change of surface temperature.

(A) Surface Heated at Constant Rate. (Steady State.)

(1) *Slab.*—From equations (39), together with (44) and (44a)

$$F = \frac{a\,h}{6\kappa\,(e\text{-}f)} (a^2 - 3x^2) \tag{47}$$

(2a) *Cylindrical tube, heated on outside only.*—From equations (42a), together with (45a), (45b), and (45c)

$$F_a = \frac{a\,h\,(a_2{}^2 - x^2)}{4\kappa\,(e\text{-}f)} + \frac{aha_1{}^2}{4\kappa\,(e\text{-}f)} \left(\ln\frac{x^2}{a_2{}^2} - 1\right) \tag{48}$$

$$F_r = -\frac{ahx^2}{16\kappa\,(e\text{-}f)} + \frac{aha_1{}^2}{4\kappa\,(e\text{-}f)} \left(\ln x - \frac{1}{2}\right) + \frac{C_1}{2} + \frac{C_2}{x^2} \tag{48b}$$

$$F_t = -\frac{3ahx^2}{16\kappa\,(e\text{-}f)} + \frac{aha_1{}^2}{4\kappa\,(e\text{-}f)} \left(\ln x + \frac{1}{2}\right) + \frac{C_1}{2} - \frac{C_2}{x_2} \tag{48c}$$

C_1 and C_2 can be immediately evaluated by placing $F_r = 0$ for $x = a_1$ and $x = a_2$.

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[61] While the equations for the sphere are exact, those for the slab and cylinder involve the assumption that end-effects can be neglected, but when the thickness or diameter is small in comparison with the other dimensions, the error introduced by this assumption is probably very small.

(2b) *Limiting case for small bored tube* (a_1 *negligible compared to* a_2).

$$F_a = \frac{ah(a_2^2 - 2x^2)}{8\kappa(e-f)} \tag{49a}$$

$$F_r = \frac{ah\left(a_2^2 - x^2 - \dfrac{a_2^2 a_1^2}{x^2}\right)}{16\kappa(e-f)} \tag{49b}$$

$$F_t = \frac{ah\left(a_2^2 - 3x^2 + \dfrac{a_2^2 a_1^2}{x^2}\right)}{16\kappa(e-f)} \tag{49c}$$

(2c) *Solid Cylinder.*—From equations (40), together with (45a), (45b), and (45c), C_3 being zero,

$$F_a = \frac{ah(a^2 - 2x^2)}{8\kappa(e-f)} \tag{50a}$$

$$F_r = \frac{ah(a^2 - x^2)}{16\kappa(e-f)} \tag{50b}$$

$$F_t = \frac{ah(a^2 - 3x^2)}{16\kappa(e-f)} \tag{50c}$$

(3a) *Spherical Shell, Heated on Outside Surface Only.*—From equations (43), together with (46a) and (46b), putting $F_r = 0$ at $x = a_1$, and $x = a_2$,

$$F_r = \frac{ah}{15\kappa(e-f)}\left\{ -x^2 - \frac{5a_1^3}{x} + \frac{a_2^5 + 5a_2^2 a_1^3 - 6a_1^5}{a_2^3 - a_1^3} - \frac{a_2^5 a_1^3 - 6a_2^3 a_1^5 + 5a_2^2 a_1^6}{(a_2^3 - a_1^3)x^3} \right\} \tag{51a}$$

$$F_t = \frac{ah}{15\kappa(e-f)}\left\{ -2x^2 - \frac{5a_1^3}{2x} + \frac{a_2^5 + 5a_2^2 a_1^3 - 6a_1^5}{a_2^3 - a_1^3} - \frac{a_2^5 a_1^3 - 6a_2^3 a_1^5 + 5a_2^2 a_1^6}{2(a_2^3 - a_1^3)x^3} \right\} \tag{51b}$$

(3b) *Limiting case for very small internal diameter* (a_1 *negligible compared to* a_2).

$$F_r = \frac{ah}{15\kappa(e-f)}\left(-x^2 + a_2^2 - \frac{a_2^2 a_1^3}{x^3} \right) \tag{52a}$$

$$F_t = \frac{ah}{15\kappa(e-f)}\left(-2x^2 + a_2^2 + \frac{a_2^2 a_1^3}{x^3} \right) \tag{52b}$$

(*3c*) *Solid Sphere.*—From equation (41), together with (46a) and (46b), C_2 being zero,

$$F_r = \frac{a\,h}{15\kappa\,(e\text{-}f)}\,(a^2 - x^2) \tag{53a}$$

$$F_t = \frac{a\,h}{15\kappa\,(e\text{-}f)}\,(a^2 - 2x^2) \tag{53b}$$

Approximate Equations for Glass (Linear Heating).—For most glasses α is about 7.9×10^{-6} per deg. C, κ is about 0.004 cm.²/sec., or 0.24 cm.²/min., and from the values of K and R (see Table I) $e - f\left(= \frac{1}{6R} + \frac{2}{9K}\right)$ is about 1.2×10^{-6} cm.²/kg. Hence, if F measured in kg/cm.² and h deg./min. (being positive for heating), we have the following approximate equations (tension being reckoned as positive and compression as negative).

Slab

$$F = 4.6h(a^2 - 3x^2) \tag{54}$$

At the middle, $x = 0$, and therefore

$$F = 4.6ha^2 \tag{54a}$$

while at the surface, $(x = a)$

$$F = -9.2ha^2 \tag{54b}$$

Solid cylinder

$$F_a = 3.4h(a^2 - 2x^2) \tag{55a}$$

$$F_r = 1.7h(a^2 - x^2) \tag{55b}$$

$$F_t = 1.7h(a^2 - 3x^2) \tag{55c}$$

Solid sphere

$$F_r = 1.8h(a^2 - x^2) \tag{56a}$$

$$F_t = 1.8h(a^2 - 2x^2) \tag{56b}$$

(*B*) *Sudden Change of Surface Temperature.*

In this case the application of the proper temperature distribution equations to the general stress equations yields, as already shown for the case of linear heating, the desired equation for the sudden change of surface temperature. Only one such equation will be given here; namely, that for the infinite slab. The combination of equations (33) and (44) leads to the relation:

Slab

$$F = \frac{2a(\theta_\circ - \theta_f)}{C} \sum e^{-\frac{\kappa Q_m^2 t}{a^2}} \left\{ \frac{1}{Q_m^2} - \frac{(-1)^{m+1}}{Q_m} \cos\frac{Q_m x}{a} \right\} \tag{57}$$

in which $C = \frac{1}{6R} + \frac{2}{9K}$, K being the modulus of compressibility, R the modulus of rigidity. The remaining symbols have the meanings already explained.

In Fig. 15 the distribution of stress in a slab 2 cm. thick, initially at 100° and suddenly plunged into a bath at 0°, is shown for several elapsed times. The stress distribution was calculated from equation (57) and the numerical values of a, κ, K and R were taken as the approximate average for various kinds of glass.

FIG. 15.
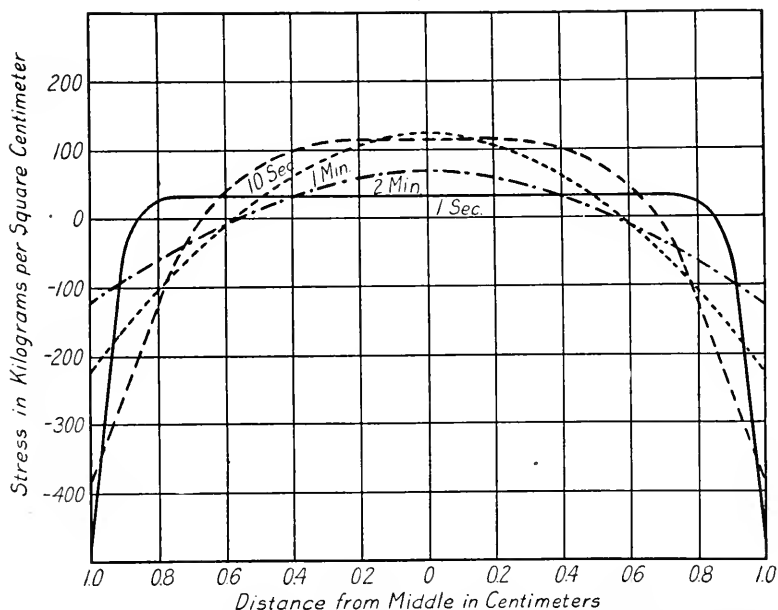
Curves showing the distribution of stress in a plate of glass 2 cm. thick which, initially at zero, is suddenly plunged into a bath at 100° C. The full line indicates the stresses throughout the glass after 1 second has elapsed; the broken line after 10 seconds; the dotted line after 1 minute; and the dot-dash line, after 2 minutes. These curves are computed from equation (57).

Optical Path Differences.

From the stress equations already given, the optical path differences as observed between crossed nicols may be readily calculated.

Some examples will be given for the case of temporary stresses due to linear heating. These formulæ also give a close approximation to the distribution of birefringence in strained glass objects such as are ordinarily encountered.

Slab.—When a slab or plate is viewed lengthwise, the longitudinal stresses in the line of sight produce no birefringence and (except near the edges) there are no transverse stresses. Hence

the observed path difference at any point is due only to the single set of longitudinal stresses normal to the line of sight, that is, parallel to the faces of the plate and perpendicular to direction of the beam of light. The stress is given by equation (54) and the birefringence is B times the stress at any point. Hence,

$$\triangle n = 4.6\,Bh\,(a^2 - 2x^2)$$ (58)

and along the middle,

$$\triangle n = 4.6\,Bha^2$$ (59)

Since B is ordinarily about 2.8 for ordinary glass (when $\triangle n$ is expressed in $\mu\mu$ per cm.), we may write

$$\triangle n = 13\,ha^2$$ (60a)

and for the optical path difference, δ, (along the middle)., we have obviously

$$\delta = 13\,ha^2l$$ (60b)

where l is the length of the block in the line of sight.

In order to verify these equations experimentally, a slab of ordinary crown glass 7.6 cm. long and 2.2 cm. thick was placed in an oven (see Fig. 5) and heated at a constant rate of 3.8 deg. per min. The optical path difference along the middle was found to be $402\mu\mu$. The birefringence was therefore $\frac{402 \times 10^{-7}}{7.6} = 52.9 \times 10^{-7}$, or $52.9\mu\mu$ per cm. The value of B for ordinary crown glass is 2.57. Hence, by equation (60a) the birefringence should have been $4.6 \times 2.57 \times 3.8 \times (\frac{2.2}{2})^2 = 54.3\mu\mu$ per cm. Another experiment with a different heating rate gave 60.2 and 60.9 for the birefringence calculated, respectively, from the heating rate and from the observed path difference.

Cylinder.—When a cylinder is viewed along its axis, the calculation of the birefringence distribution is simple. In this case the axial stresses produce no effect, and the path difference is due to difference of the radial and tangential stresses. Hence, from equations (55b) and (55c)

$$\triangle n = 3.4\,B\,h\,x^2$$ (61)

The sign of the birefringence is such that for a cylinder which is being heated or for a cylinder which is permanently strained, γ (the greater index) is in the radial direction.

As an example of the use of equation (61) we cite the follow-ing observation: A section of a cylindrical glass rod 2.0 cm. in diameter, when viewed lengthwise, showed at the surface a birefringence equal to 2.1×10^{-4} (2100$\mu\mu$ per cm.). The rod was of soda lime glass of unknown composition, but it is safe to assume that the value of B is not far from 2.8. Hence, by equation (61) the value of h is $\dfrac{2100}{2.8 \times 34 \times 1^2} = 220$ deg. per min. That is, after being drawn this glass rod must have been cooled through the

FIG. 16.
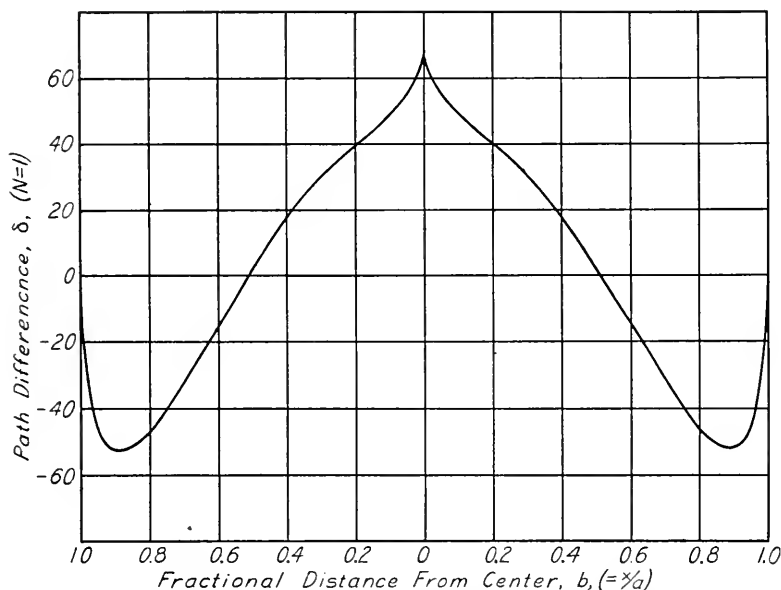
This, the graph of equation (62), shows the optical path difference, δ, when a beam of light passes through a strained cylindrical rod in a direction normal to the axis. Reflection of light at the surface is supposed to be prevented by immersing the rod in a liquid of the same refractive index.

annealing range at a rate of about 200 deg. C. per minute. It is of interest to note that, according to equation (55c) the stress at the surface of this glass was $3.4 \times 220 = 750$ kg/cm.[2]

When the cylinder is viewed in a direction normal to the axis the problem is much more complicated. In this case the observed path difference is due to the axial stress and to the components (in a direction normal to the line of sight and to the axis) of

the radial and tangential stresses. Performing the necessary substitutions and integrating along a chord, we find that

$$\frac{\delta}{N} = b - b^3 + \sqrt{1 - b^2}\left(\frac{2}{3} + \frac{b}{2} - \frac{8b^2}{3}\right) + \left(-\frac{b}{2} + \frac{b^3}{4}\right)\ln\frac{1+\sqrt{1-b^2}}{1-\sqrt{1-b^2}} \quad (62)$$

in which δ is the path difference along a chord whose distance from the centre is x; b is equal to x/a, a being the radius; and

$$N = \frac{a\,hBa^3}{8\,(e-f)\,\kappa}$$

In Fig. 16 is shown the graph of equation (62). A qualitative check on the validity of this equation was obtained by placing

Fig. 17.
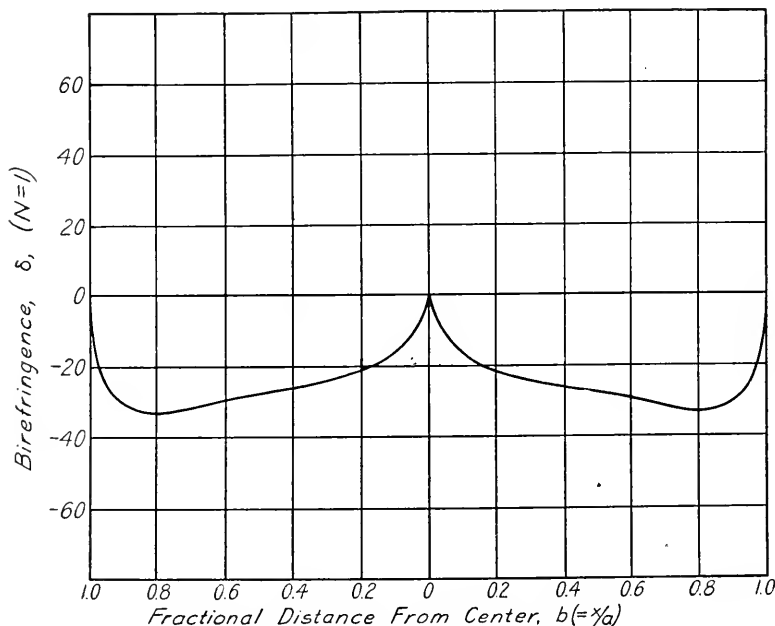
Curve (graph of equation 63) showing optical path difference, δ, when a beam of light passes through a strained sphere. The value of N (as also in Fig. 16) is taken as unity.

a strained glass rod in a square glass jar, surrounding the rod with liquid of the same refractive index and viewing it between crossed nicols. The sign of the path difference is such that near the middle of the strained rod α is normal to the axis.

Sphere.—The path differences in this case are due to both the radial and the tangential stresses, and the equation which re-

sembles that for the cylinder viewed normal to the axis, is as follows:

$$\frac{\delta}{N} = -\frac{1}{3} + b - \frac{2}{3}b^3 + \sqrt{1-b^2}\left(\frac{1}{3} + \frac{b}{2} - \frac{4b^2}{3}\right) +$$

$$\left(-\frac{b}{2} + \frac{b^3}{4}\right)\ln\frac{1 + \sqrt{1-b^2}}{1 - \sqrt{1-b^2}} \qquad (63)$$

in which

$$N = \frac{2\alpha\, hBa^3}{15\,(e-f)\,\kappa}$$

the remaining symbols having the meanings already explained. γ is always in the radial direction. Fig. 17 is a graph of this equation which was qualitatively verified by observing Prince Rupert drops immersed in a liquid of the same refractive index.

CONCLUDING REMARKS.

Variation of Physical Constants of Glass with Temperature.— It should be borne in mind that in dealing with the temperature gradients in glass and with the stresses arising from these gradients, we have assumed that the expansion coefficient, α, and the thermal diffusivity, κ, do not change with temperature. This assumption was made in order to simplify the mathematical treatment, but it is well known that both of these quantities are affected by temperature changes. Indeed, as mentioned above, the expansion coefficient shows a pronounced change near the upper end of the annealing range. Between room temperature, however, and a temperature slightly below the upper end of what we have defined as the annealing range, it appears as if both α and κ were sufficiently constant to enable our equations to give a fair approximation to the amount of strain incurred by various cooling procedures. The experiment (described above, p. 841) in which a slab of glass, when cooled at an approximately uniform rate through the annealing range showed the expected amount of permanent strain, would seem to be good presumptive evidence that, at least for practical purposes, our assumption of the constancy of α and κ leads to sufficiently correct equations. The statement of Peters and Cragoe [62] : " It seems probable that most of the strains that exist in a piece of glass are introduced when it cools through the critical region," is not in accord with our ex-

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[62] *Loc. cit.*, p. 142.

perience. In fact, anyone who will take the trouble to cool a piece of glass at a uniform rate from a temperature above the softening point, observing at the same time the strain in the glass, can satisfy himself that no important amount of strain is introduced in the critical range, so long as the cooling rate remains constant. Whenever the cooling rate decreases, however, the appearance of strain may be noticed.

That the sudden change in expansion coefficient should not be instrumental in introducing strain in the critical region seems to us to be due to the fact that it occurs at a relatively high temperature, so that the strains momentarily introduced by the change in α are relieved at a rapid rate. For example, from the results of Peters and Cragoe it appears that with light barium crown glass No. 11 (nearly identical with our light barium crown), comparatively little change in expansion coefficient takes place below 560°. Now if a piece of this glass were to cool down to 560°, acquiring strain as it cooled, the greater part of this strain would disappear in a few minutes, for even at 560° a large stress would be reduced to $10\mu\mu$ per cm. in less than 15 minutes. It is evident, therefore, that except for very rapid cooling, which would entail large temperature differences between the inside and the outside of the glass, the sudden change in the expansion coefficient is not likely of itself to introduce much strain, nor, in our opinion, to destroy the utility of the temperature and stress relations which we have recorded in this paper.

Ability of Glass to Withstand Changes in Temperature.—An important part of the technic of annealing glass consists in heating and cooling the glass in the shortest possible time. Now, it can be seen by inspection of equations (54) *et seq.*, that in general, when a piece of glass changes temperature, the maximum stresses occur at the surface. Furthermore, their direction is parallel to the surface, *i.e.*, they are tangential or longitudinal stresses. Thus, at the surface of a sphere when heating there is tangential compression, and when cooling, tangential tension. It is well known that the strength of glass under tension is much less than that under compression. The tensile strength of glass is seldom above 1000 kg/cm.², the average being about 600 kg/cm.², while the compressive strength may be several thousand kg/cm.². It follows, therefore, that glass articles should withstand much more violent thermal increases than decreases. This

conclusion is in accord with the well-known fact that glass cracks more easily when cooled than when heated. In the practical annealing of glass it is not often that glass is fractured by too rapid heating; indeed, it would be difficult, if not impossible, to heat the ordinary annealing furnace or muffle too rapidly; while, on the other hand, the cooling rate may easily become excessive, and should be regulated carefully. As already explained, in order to allow a fair factor of safety optical glass slabs should never be cooled at a rate greater than $10/a^2$ deg. C. per minute, a being the semi-thickness of the slab.

The permanent stresses occurring in an unannealed piece of glass are qualitatively the same as the temporary stresses produced by heating, *i.e.*, longitudinal or tangential compressions at the surfaces. This means that when cutting strained glass, enough extra tension must be applied at the crack or cut to neutralize the compressive force and then to exceed the tensile strength of the glass. Highly strained glass would therefore be difficult to cut up into pieces (as, for example, with a diamond). As illustrative of this fact, all attempts to cut a glass rod showing strain to the extent of $2000\mu\mu$ per cm. completely failed, and it could be broken only by blows from a heavy hammer.

SUMMARY.

The manner in which temporary and permanent stresses arise in glass is discussed. It is shown that the process of annealing glass can best be carried out if we know for the various glasses and for the various temperatures the rate of release of the internal stresses. Such measurements for nine kinds of glass are here presented. The release of stress at constant temperature was found to proceed usually according to the equation

$$\frac{1}{F} - \frac{1}{F_0} = At$$

in which F is the stress at any time, t, F_0 is the initial stress, and A is a constant for the particular glass at a particular temperature, and is a measure of the rate at which stresses are relieved. The variation of this rate with temperature follows the equation

$$\log A = M_1 \theta - M_2$$

in which M_1 and M_2 are constants for a particular glass.

At any temperature, a glass requires a certain *annealing time*. This is arbitrarily defined as the time required to reduce the stress

(in optical units) from 50 to 2.5$\mu\mu$ per cm.   For convenience of reference, the 150° interval of temperature lying immediately below the temperature at which the annealing time is 2 minutes is called the *annealing range*.   At temperatures below the annealing range, as thus defined, very little permanent stress can be introduced.

Concrete directions are given for annealing various kinds of glass.   It is shown that the best method for annealing requires that the glass be held at constant temperature (below the customary annealing point) for the appropriate time and then cooled at an increasing rate.

Finally, there are presented a number of equations which are convenient for calculating the stresses due to heating or cooling various shapes of glass.

Geophysical Laboratory,
    Carnegie Institution of Washington,
        Washington, D. C.,
            September 1, 1920.

Desert Watering Places.   (*U. S. Geological Survey Press Bulletin No. 459,* November, 1920.)—Every year the "American Desert" takes its toll of human life.   In many parts of it springs, wells, and water holes are few and far between.   Three years ago the United States Geological Survey, Department of the Interior, under a small special appropriation by Congress, erected signposts in the worst portions of our southwestern deserts, giving directions and distances from watering place to watering place.   This life-saving work of the Geological Survey was supplemented by a survey of these deserts in coöperation with the California Department of Engineering, the results of which are being published in a series of guidebooks.   A guide just issued, entitled "Routes to Desert Watering Places in the Salton Sea Region, California," by J. S. Brown, contains maps of roads and watering places and road logs giving mileage and notes as to supplies obtainable.

Congress for the Management of the Streams in the Garonne Basin.—*Le Génie Civil* in the issue of July 31st announces that this meeting will be held at Bordeaux in 1921 under the presidency of Senator Claveille, former Minister of Public Works.   The discussions will relate to the employment of streams for the development of power, for navigation, and for irrigation.   The extensive project already adopted for the Rhone valley has, no doubt, been an incentive to the people living in the territory draining into the Bay of Biscay.

G. F. S.

A PRODUCTION OF PANCHROMATIC SENSITIVENESS WITHOUT DYES.*

BY

J. G. CAPSTAFF and E. R. BULLOCK.

Eastman Kodak Company.

In the course of some experimental work carried out by one of the writers in 1917 with ordinary plates in which the plates were being bathed in certain solutions prior to exposure, it occasionally happened that the emulsions fogged badly on development. The cause of the fogging was puzzling, because the plates that showed the defect had apparently had the same treatment as those that developed clean. Investigation showed that the treatment undergone by the plates had rendered them panchromatic and that their erratic behavior regarding fog was mainly due to the time they had been exposed to the red light of the dark room which had been considered safe with the type of emulsion being experimented with before receiving the treatment referred to.

By a process of elimination it was finally discovered that the color sensitizing was caused by the use of a sodium bisulphite bath followed by a lengthy washing. As the phenomenon was thought to be new and to be of theoretical interest, work was commenced to determine the conditions which conferred the maximum color sensitiveness and, if possible, to explain the effect.

Considerable work has from time to time been devoted to the problem, but to date no entirely satisfactory hypothesis has been evolved, the most plausible being that the treatment results in a partial reduction of the silver salt to colloidal silver, which is known under certain conditions to act as an optical sensitizer. The work is being continued, and a detailed account of the experiments will be given later. It is thought, however, that a brief summary of the most fruitful experiments carried out so far will be of interest.

The effect is not peculiar to any one type of emulsion, but most of the trials were made on Eastman Commercial film. Fig. 1

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is a wedge spectrograph showing the normal spectral sensitiveness of this emulsion.

In one experiment six pieces of film were bathed in 2 per cent. sodium bisulphite for ten mintes, the temperature being 70° F. They were then washed in running tap water (temperature about 60° F.) for the following times:

1.	Washed	5	minutes.
2.	Washed	15	minutes.
3.	Washed	1	hour.
4.	Washed	5½	hours.
5.	Washed	24	hours.
6.	Washed	30	hours.

All were allowed to dry spontaneously hanging in a well-ventilated dark room. The temperature averaged 70° F.

Wedge spectrograms showed progressively increasing color sensitiveness with washing time. Figs. 2 and 3 illustrate the first and last of this series.

The fog density increased with the color sensitiveness, varying, with normal development, from .07 in number one to .41 in number six.

A similar series washed in distilled water showed only the normal sensitiveness and washing in tap water without the preliminary bisulphite treatment gave a degree of color sensitiveness so slight that its existence was overlooked in the earliest experiments but which was subsequently found to be invariably produced on prolonged washing. Soaking in a large volume of water or solution (e.g., 2 litres for one 3¼ x 4¼ film) was always found to have the same effect as washing in running water, provided that in each case the temperature was the same. Tap water boiled down to various extents and then cooled was found to have very much the same effect as untreated tap water.

The addition of alkali to the tap water reduced the time of washing necessary and increased the general sensitiveness. The film of spectrogram number four had the following treatment:

Sodium bisulphite 5 per cent.	10 minutes.
Washing	5 minutes.
N/10 sodium carbonate	10 minutes.
Washing	5 minutes.

It was later found, however, that even better results were produced by a 0.2 per cent. distilled-water solution of

pure potassium bicarbonate which was neutral to litmus and free
from chlorides.

Sodium sulphite as the preliminary bath apparently has no

FIG. 1.

FIG. 2.

FIG. 3.
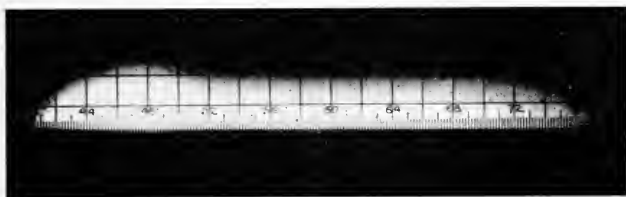
FIG. 4.
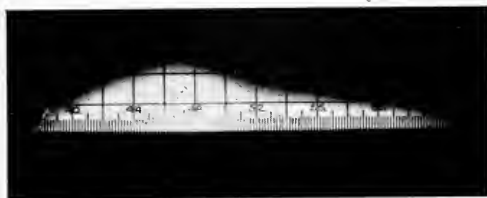
action. Sulphurous acid has. It seems then that the effect is
due to the sulphurous acid content of the sodium bisulphite solu-

tion. This is confirmed by the fact that the addition of a little sulphuric acid to the bisulphite accentuates the action of the bath.

Extremely small percentages of soluble bromides or chlorides in the washing water or the carbonate bath diminish the effect, and .004 per cent. of potassium bromide or .2 per cent. of sodium chloride is sufficient to prevent color sensitizing entirely. No noticeable restraining action occurs, however, if these are present only in the bisulphite.

Numerous other experiments were tried with more or less inconclusive results and the investigation so far has given so many inconsistencies that the writers prefer to pursue the work further before discussing the matter in fuller detail.

Rochester, N. Y.,
    May 14, 1920.

On the Application of Interference Methods to Astronomical Measurements. A. A. Michelson. (*Comptes Rendus*, July 5, 1920.)—Attention is directed to an article published in 1896 where the author proposed a method of measuring such astronomical magnitudes as the diameters of planetoids and satellites, the angular distance between double stars and, perhaps, even the diameters of fixed stars. To do this it was suggested that a series of interference bands be formed at the focus of a telescope by the light from two slits, illuminated by the source of light under investigation. These slits were to be located at the ends of a diameter of a large telescopic objective. The fringes would consist of equidistant bands whose sharpness would be greatest for a point source of light. The angular diameter of the source can be obtained from a study of the distribution of the light in the bands. From a knowledge of the manner of distribution of light in the source the arrangement of light in the bands may be calculated and, conversely, from the latter the former may be inferred.

This method was applied to Capella at the Mount Wilson Observatory and gave satisfactory results. The parallax of this star was found to be a little less than .05 sec. of arc. With a base 250 cm. long an accuracy of .001 sec. is to be counted on. In this experiment the slits were actually put near the eye-piece and not in front of the objective. The fringes remained very fixed and clear in spite of much boiling.

Professor Michelson expects this work to continue with an interferometer base about 6 m. long, and, if these preliminary experiments warrant it, with even a longer base.

                                                        G. F. S.

The progress of the American coal-tar chemical industry during 1919 is outlined by GRINNELL JONES, Chief Chemist of the U. S. Tariff Commission, in *Journ. Indus. and Eng. Chem.,* 1920, xii, 959–961. The output of pure benzene and pure toluene decreased, since mixtures of these hydrocarbons were distilled from the tar for use as solvents and as motor fuels. The production of refined anthracene falls far below the amount required to meet the domestic demand for alizarin and vat dyes. Removal of anthracene from the tar leaves the pitch so hard that its market value is greatly reduced. The output of certain coal-tar intermediates, used primarily in the manufacture of explosives or of khaki dyes, underwent a marked decrease. The total number of intermediates, manufactured in the United States, increased from 140 in 1918 to 225 in 1919; these compounds are used in the dyestuff industry and in the preparation of synthetic drugs. Slightly more than 63,000,000 pounds of dyes were made in 1919, approximately 8 per cent. more than were produced during the previous year. The dyes improved considerably in quality. Of the three photographic developers—hydroquinone, metol, and para-amino-phenol—the total production in 1919 was about 195 tons.

J. S. H.

The Reproduction of Speech by Galena and Undamped Waves. P. COLLET. (*Comptes Rendus,* June 7, 1920.)—As far back as 1913 Brazier and Dongier showed that the passage of a sufficiently strong alternating current across the surface of contact of a metal point with a crystal of galena caused a sonorous effect. The present investigator in continuing these experiments used a primary circuit in which undamped waves were set up and a secondary circuit, entirely separate from the primary, and tuned to it by means of a variable condenser. From the terminals of this run off two line wires several meters long. At the end of one wire is a crystal of sensitive galena, while a platinum point is at the extremity of the other. The point touches the galena, thus forming a circuit shunting the condenser. Furthermore, the point is fixed to the centre of a phonograph disc mounted on the horn of the instrument. Let the secondary circuit be tuned to the primary, and let the latter be periodically interrupted by a tuning fork. The phonograph then emits a note of the same pitch as the fork. When a carbon microphone was joined in the secondary circuit, the sounds of a voice speaking in front of it were reproduced in an adjacent room with great intensity and with remarkable fidelity in quality. The singing voice is likewise admirably rendered in all detail.

There is no advantage gained by using loud voices or intense currents. The phenomenon is attributed to thermal effects, being kindred to the Trevelyan rocker made well known in America by Professor Tyndall half a century ago.

G. F. S.
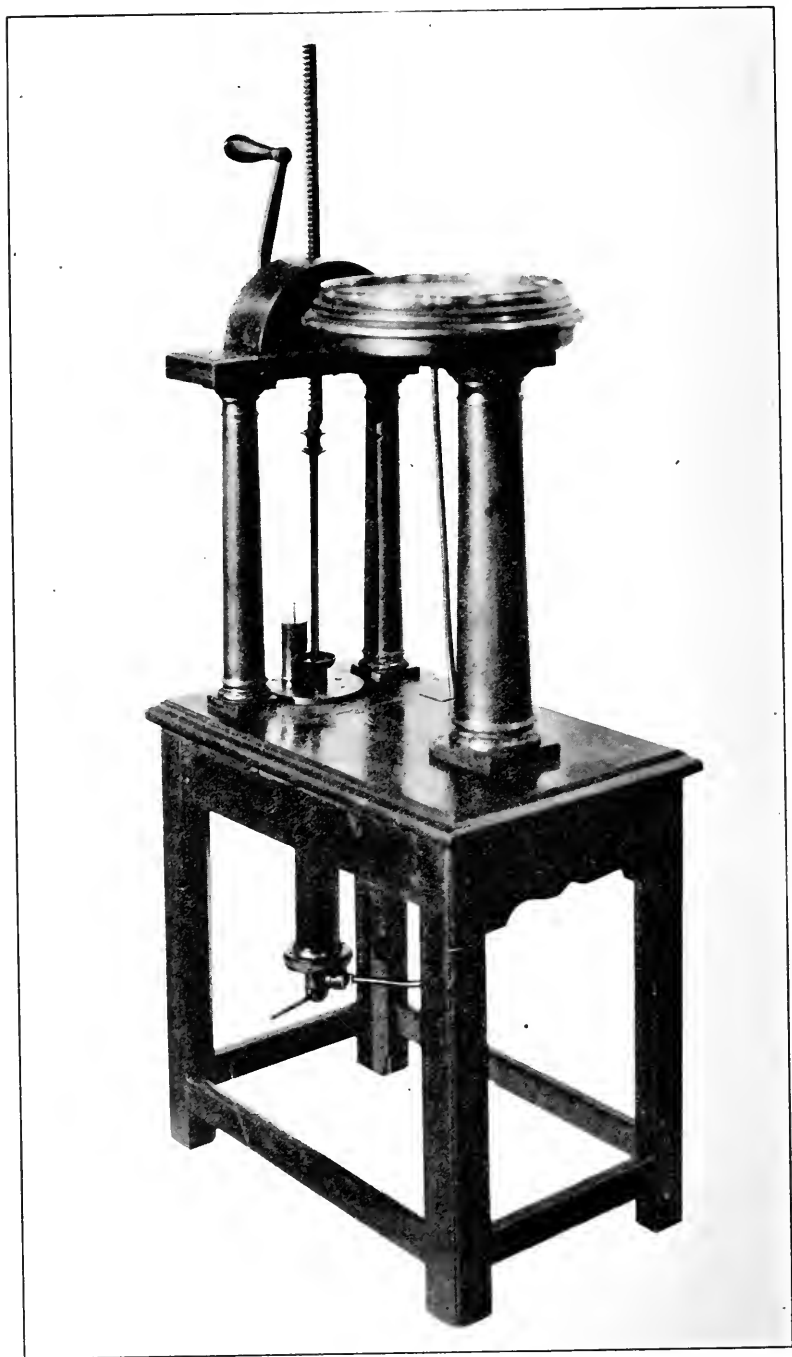
The Priestley air pump

THE PRIESTLEY AIR PUMP.

PRESENTED BY

COLEMAN SELLERS, JR., and HORACE W. SELLERS.

In presenting to the Institute, at its Stated Meeting held Wednesday evening, October 20th, the air pump, once the property of Dr. Joseph Priestley, shown on the opposite page, Mr. Coleman Sellers, Jr., made the following remarks:

Mr. President, members of The Franklin Institute, ladies and gentlemen: Before considering this ancient piece of philosophical apparatus, it may add to its interest, if we recall to memory some facts about the remarkable man to whom it formerly belonged.

Dr. Joseph Priestley is recollected chiefly as the discoverer of oxygen; but this accomplishment by no means comprises all of his contributions to science, for he also discovered and experimented with many other gases; but the curious part of the matter is that his scientific work was his avocation, or pastime. By profession, he was a controversial non-conformist clergyman, and a prolific writer and lecturer on theological and other topics. He was an ardent political reformer, and it was to his political activity in an unpopular cause that we owe his exile to America, which has finally brought this historic air pump to a permanent home in the collection of this Society.

Doctor Priestley was born in Yorkshire, near Leeds, March 13, 1733, his father being Jonas Priestley, weaver and dresser of cloth. From 1742 to 1764 he made his home with an aunt who sent him to school, where he learned Latin and Greek. He studied Hebrew in his holidays, so that when he was about sixteen years old, he claimed to have a pretty good knowledge of the ancient languages. He came of a strongly religious family, and it was his intention to enter the ministry; but lung trouble for a time deterred him from this course and he took up the study of modern languages, learning French, Italian and German.

He also studied mathematics, logic and natural philosophy. He learned Hebrew, Chaldee, Syriac, and began to read Arabic. In 1755 he became assistant to a superannuated minister for a compensation of 30 £ sterling per year; and in 1758 he assumed the pastorate of a church near old Chester. His congregation was

small and his duties not burdensome, so he opened a school for about thirty boys and six girls and taught daily from 7 A.M. to 4 P.M. with one hour for dinner and no holidays. After school hours, he had private pupils.

He was now able to buy a few books and even an air pump and an electric machine, and it was through this apparatus that his interest in experimental science began. Incidentally he wrote and lectured on many subjects covering various phases of political economy, government, civil law, logic, anatomy and Hebrew.

During a visit to London, he met and formed a strong friendship with Benjamin Franklin, who, undoubtedly exercised a powerful influence in shaping Priestley's future life. He offered to write a history of electricity, if Doctor Franklin would furnish him the necessary books. This he gladly did, and the work was published in 1767, under the title of " The History and Present State of Electricity, with Original Experiments Illustrated with Copper-plates." Much of this work was original matter, the result of his own experiments, and although the laboratory work and composition were done in the leisure time of a busy clergyman, he was able within a year to send to Doctor Franklin a printed copy of the book. It is worthy of mention that during this year, he spent five hours a day lecturing and took a two months' vacation. This book resulted in his election as a Fellow of the Royal Society.

He was ordained a minister in 1762 and in 1767 became pastor of a congregation in Leeds, at a salary of 100 guineas and a house. His wavering heterodoxy built on a Calvanism, which he did not find convincing, finally settled into Unitarianism and he became one of the chief upholders of heterodoxy in religion and of advanced ideas in politics.

It was at Leeds that he began his work on gases. He started with a study of " fixed air," or carbon-dioxide, and invented soda water, which he suggested might be useful in medicine. He made his first publication on gases in 1772, for which he was awarded the " Copley Medal," and in succession he discovered nitrous oxide, hydrochloric acid gas, nitric oxide, oxygen (in 1774), ammonia gas, sulphur dioxide, silicon fluoride and nitro-sulphuric acid.

It is not to be understood that he recognized these substances by the names we now call them. Oxygen, he knew as " dephlogisticated air." In fact, his philosophy was usually vague and his

reasoning defective, largely perhaps because he was influenced by the prevalent theories of the time, and also it has been suggested, by defects of memory. He often forgot his own notes, and his own publications. In his cheerful way he suggested that this defect was· in a measure compensated for by facility in " invention or new and original combinations of ideas." He was much more interested in trying experiments than he was in philosophic deductions from the facts observed.

Priestley was a real discoverer, a brilliant experimenter, an indefatigable investigator. He proved by experiment " that plants are perfectly capable of restoring air injured by respiration " ; and he made some measurements of the oxygen absorbed and the carbon-dioxide evolved during respiration.

His busy and useful life was disturbed in 1791 by the Birmingham Riots, which were precipitated by a demand for the repeal of the Test Act. Priestley was active in this movement and also sympathized with the French Revolution. When an attempt was made to celebrate the fall of the Bastile on July 14, 1791, by a public banquet, the hotel was attacked by a mob, which broke the windows and then proceeded to Priestley's church, the " New Meeting," which was sacked and burned, as was also the " Old Meeting." Burning of non-conformists' churches and ministers' houses continued, and Priestley was hurried to London, where he was taken charge of by his friends.

He was offered a pulpit, but felt that his usefulness in England was ended, and he concluded to join his sons in America. He sailed for New York, April 8, 1794, proceeded to Philadelphia and then to Northumberland, Pa. Soon after his arrival in Philadelphia, he was offered the professorship in chemistry at the University, which he declined, and in 1803, it was proposed to make him Provost of the University. This he also declined on account of his advanced age. In America he resumed his scientific work ; but made no new discovery of importance, although he published a number of papers. He died February 6, 1804.

When he came to America, he brought with him such of his apparatus as he could, and among other things was the air pump which we have before us.

As to the history of the pump since Doctor Priestley's death : My father's correspondence [1] shows that it was procured by his

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[1] Coleman Sellers, E.D., D.Sc. (1827–1907), President of The Franklin Institute, 1870–1874.

brother Charles,[2] who was a friend of the Priestleys, for use in some lectures which he was delivering in Cincinnati. When he left that city about 1849, he turned his philosophical apparatus over to his younger brother Escol,[3] who subsequently removed to southern Illinois.

In 1897, at my father's request, Escol Sellers sent him the air pump, which apparently had never been used while in his possession. Escol wrote that when his brother Charles got the pump, the valves and pump chamber were in bad shape, and he worked a long time to put them in order. He said that on the frame, there was a portion of a bone or ivory name plate, on which they made out the words " Adams " and " London," which they inferred to have been the name of the maker and his address.

We all value this relic highly and my brother [4] and I have felt anxious to transfer our responsibility as its custodians to that association which would most appreciate it, and would give it the best care.

We have concluded that the most appropriate custodian is The Franklin Institute of the State of Pennsylvania, and we feel sure that we are putting the old pump in safe and appreciative hands.

I take pleasure, Mr. President, in delivering to the Institute, over which you so ably preside, this ancient relic and memento of a remarkable man, with the full assurance that it will be guarded and preserved with the respect it deserves.

The Dye-works Chemist.—According to B. Leech (*Jour. Soc. Chem. Ind.*, 1920, xxxix, Review, 300–302), the chemist in a British dye-works should have a broad scientific training in a university, supplemented by special training in a technical school. Among the problems which he may have to solve are: plan of buildings and proper materials for their construction; ventilation of the plant; weaving goods " in the gray " and dyeing the woven piece; special treatments, such as weighting of silk and mercerization of cotton; production of artificial fibres; treatment of fabrics to render them fireproof, waterproof, or non-permeable to gases, and many procedures which involve organic colloidal, and biological chemistry, mycology, physics, and engineering.

J. S. H.

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[2] Charles Sellers (1806–1898).

[3] George Escol Sellers (1808–1899).

[4] Horace Wells Sellers, F.A.I.A.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

STEEL RAILS FROM SINK-HEAD AND ORDINARY RAIL INGOTS.[1]

By George K. Burgess.

[ABSTRACT.]

THE object of this investigation was to determine the relation of ingot practice to the properties of rails from such ingots, and in particular to determine the amount of total discard necessary to obtain rails free from piping and segregation above 12 per cent., which has been rolled from steel made in accordance with varying melting, casting and ingot practices.

To that end 35 ingots, made by the converter process at Hadfield's, Sheffield, England, and cast by the sink-head process with large end uppermost, were shipped to Sparrow's Point, Md., and rolled into rails; these were compared with 15 rail ingots made in the ordinary manner with the small end uppermost. Each sink-head ingot, of about 5300 lb. weight, and deoxidized with aluminum in the mold, represented a separate heat of converter steel, and all the heats and ingots were made in the same manner. The composition and properties of these ingots were of remarkable uniformity. The comparison ingots, of 7300 lb. each, were from three separate open-hearth heats, an additional variation being made in the casting and open-hearth practice for each. Five ingots were selected from each of these three heats. Thus, in reality, comparison was made of four different kinds of steel of very nearly the same composition and physical properties and of two types of ingot form.

The comparison was made by rolling most of the ingots into rails and taking test specimens at each rail cut, as well as from a considerable portion of the upper part, in five-foot steps, of the rail bar from each ingot. In this way there was obtained a detailed physical, chemical and metallographic survey of each ingot, and it was possible to exactly delimit the regions of sound and homo-

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* Communicated by the Director.
[1] Technologic Paper No. 178.

geneous, from those of unsound and segregated, steel. Two complete sink-head ingots were cut longitudinally and examined, as also were representative blooms from both sink-head and ordinary ingots.

The results obtained indicate a decided superiority of the sink-head ingots over the comparison ingots as made of three grades of steel (Tables 17 and 18), although the sink-head ingots suffered from the disadvantage of having gone cold before rolling. The Hadfield type of ingot required a total discard of only 18.4 per cent. on the average (13 per cent. top discard to eliminate piping and segregation above 12 per cent.), while the average ingot of the ordinary type for rails required a total discard of 43.9 per cent. (26 per cent. top discard), with great variations dependent upon the furnace and ingot practices.

The comparison ingots from heat M1–M5, made of non-deoxidized rising steel chilled on top of ingot by cast-iron caps, required excessive discard to eliminate positive segregation at the top and negative segregation at the bottom of the ingot, the latter often accompanied by dangerous enclosed pipes.

The second heat (M6–M10), made of rising steel deoxidized with aluminum in the molds, the ingot tops of which were cooled with water, required the least total discard of the three heats. It was more subject to piping and less to segregation than the first heat of ingots made in the usual manner.

The third heat (M11–M15), made of quiet or " killed " steel, was not chilled on top with water nor caps and was deoxidized with aluminum in the molds. The ingots of this heat required an intermediate amount of total discard when compared to the first and second heats; this heat was the only one for which a greater top discard was required to eliminate piping than to eliminate segregation above 12 per cent. One of the ingots of this third heat contained a small pipe at the bottom and all the rails from the middle and bottom of the ingots showed high negative segregation.

The distribution of physical properties throughout the length of each ingot is characteristic not only of the type of the ingot, as sink-head or ordinary, but also of the state of the steel when cast, and of the ingot practice.

It has been established in the foregoing, that after removal of the top discard of 13 per cent., the Hadfield type of sink-head

ingot is free from piping and undue segregation. The ordinary type of ingot, cast small end up without sink-head as is usual for rail ingots, requires an average top discard of 26 per cent. and the remainder of the ingot is liable to contain enclosed piping and excessive segregation. Defective rails, from the middle and bottom portion of the ingot, are not certainly detected by means of existing rail specifications, and as a result of this uncertainty, rails containing pipes or excessive segregation may get into service with disastrous results.

The surface condition of the rails from the sink-head ingots was not so good as for the ordinary ingots, but this is not considered an essential characteristic of rails from such ingots.

The markedly differing characteristics of the three heats of comparison ingots leads one to raise the question whether or no it might be advisable to specify, at least in some degree, the methods of steel manufacture or of ingot practice for rails and similar products on which the safety of the travelling public depends.

While it is not claimed that the use of the sink-head process for the manufacture of ingots will solve all rail problems, it is maintained that its adoption would be a step in the right direction in view of the present heavy casualties and property losses on American Railroads. The necessary changes in mill operations, it is believed, could be made without too great difficulties.

SULPHUR IN PETROLEUM OILS.[2]

By C. E. Waters.

[ABSTRACT.]

Short accounts are given of the theories concerning the origin of the sulphur and sulphur compounds which are found in crude petroleum. The forms of combination in which the element occurs, their identification and significance are briefly discussed.

Tests for the detection of sulphur are described, and the copper test is shown to be one of great delicacy. Although it will show the presence of very minute amounts of free sulphur or of hydrogen sulphide, it may be of no value at all when the sulphur is in stable organic compounds.

Various methods that have been used for the determination of

[2] Technologic Paper No. 177.

sulphur in oils, and finally a new procedure, are described. The new method is based on the preliminary treatment of the oil with nitric acid saturated with bromine, followed by fusion with a mixture of sodium nitrate and carbonate. Certain sources of error which are inherent in the method and the way in which they can be corrected for, are taken up.

Data obtained by the analysis of certain oils by this and other methods are given. From these it appears that there is no loss of sulphur when oil is treated with nitric acid and bromine, and then ignited with the fusion mixture. The method is recommended for laboratories which do not have a bomb calorimeter.

INFRA-RED TRANSMISSION AND REFRACTION DATA ON STANDARD LENS AND PRISM MATERIAL.[3]

By W. W. Coblentz.

[ABSTRACT.]

Transmission curves of quartz, fluorite, rock salt, and sylvite, etc., are given, and the suitability of these substances for prisms, with especial reference to infra-red spectro-radiometry, is discussed. Tabulated data are given of the refractive indices of these materials. The paper discusses also the construction and methods of calibration of spectroradiometers.

SLUSHING OILS.[4]

By P. H. Walker and Lawrence L. Steele.

[ABSTRACT.]

Slushing oils are materials used for protecting bright metal where it is not practical to use paint, varnish, or other fixed coatings. An ideal slushing oil is one which can be easily applied to all kinds of metal surfaces by a variety of methods. It should coat the surfaces with a sufficiently thick and impervious film to exclude moisture and air (to prevent rusting), should remain in position for an indefinite length of time, and yet be completely removable from the surface without undue labor. The material should itself have no corrosive action on any kind of metal.

This paper contains a discussion of properties and methods of testing, most of which were developed in the course of this investi-

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[3] Scientific Paper No. 401.
[4] Technologic Paper No. 176.

gation, and summarized results of tests of a number of samples. From a study of numerous laboratory and exposure tests proposed specifications are given. The specifications suggested are based upon properties of the finished product rather than chemical composition. Formulas are given of some satisfactory mixtures, but it is not claimed that these are the best slushing oils that can be made. They are merely cited as examples of easily made preparations which were found to protect metal.

TESTS OF BOND RESISTANCE BETWEEN CONCRETE AND STEEL.[5]

By W. A. Slater, F. E. Richart and G. G. Scofield.

[ABSTRACT.]

This paper includes reports of three separate series of tests:

1. Tests to determine the effect of preservative coatings on bond resistance of reinforcing bars embedded in concrete.

2. Tests to determine the length of the lap which is necessary in order to secure the effective splicing of bars by lapping in regions of high tension.

3. Tests to determine as to the effectiveness of the anchorage of stirrups in the flanges of T-beams when the loads on the beams are placed in such a way as to put tension across the plane of connection between the flange and the stem of the beam.

The tests with preservative coatings indicate:

1. The maximum bond stress developed by bars which were painted, was generally considerably less than the bond resistance of unpainted bars, but the reduction in maximum bond resistance due to galvanizing and some similar processes was less than that due to painting.

2. Coated deformed bars apparently slipped considerably before the corrugations or lugs reached a firm bearing. After a bearing had been secured the increase of resistance with increased slip was similar to that which took place with uncoated deformed bars.

3. The bond resistance at a slip of 0.001 in. was a much smaller proportion of the maximum bond resistance for coated bars than for uncoated bars.

The tests of beams with lapped bars indicated that:

1. Proceeding along a lapped bar towards its unanchored end

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[5] Technologic Paper No. 173.

from the point where the stress in the bar began to diminish the stress lost from this bar was picked up by the other bars of the beam. In a majority of cases a slightly larger amount of the stress lost by the lapped bar was picked up by bars immediately adjacent than by other bars of the beam.

2. A lap of about 48 diameters of the bar was necessary to secure a satisfactory splice. The bars used were ½ in. in diameter and the concrete had a strength of about 5000 lb. per sq. in. Alongside the lapped bars were unspliced bars which extended throughout the total length of the beam.

The pull-out tests of stirrups indicated that right-angle hooks formed by bending through 90° were not as effective for anchorage as right-angle hooks bent through 270°. The anchorage was less effective when the loop formed by the 270° turn was kept empty than when it was filled properly with concrete.

THE IONIZATION AND RESONANCE POTENTIALS OF SOME NON-METALLIC ELEMENTS.[a]

By F. L. Mohler and Paul D. Foote.

[ABSTRACT.]

Measurements of the critical potentials were made in four electrode vacuum tubes by methods similar to those previously used by the authors. The essential features of the methods are the detection of the resonance potential by the occurrence of inelastic electron collisions and the ionization potential by the presence of positive ions. The following table gives the results obtained. The theoretical values for hydrogen are derived from Bohr's theory for atomic and molecular hydrogen.

Summary of Critical Potentials of Gases and Vapors.

Element	Resonance		Wave-length	Ionization		Wave-length
	Observed	Theoretical		Observed	Theoretical	
			λ in Å			λ in Å
Phosphorus.......	5.80	....	2130	13.3	....	928
Iodine...........	2.34	....	5300	10.1	....	1220
Sulphur..........	4.78	....	2580	12.2	....	1010
Nitrogen........	8.18	8.270	1492.8 1494.8	16.9	....	730
Oxygen..........	7.91	....	1560	15.5	....	796
Hydrogen........	10.40 12.22	10.16	1215.6	13.3 16.5	13.54 16.26	911.78

Italicized wave-lengths are computed from observed potentials. The others are the spectroscopic values from which theoretical potentials have been computed.

[a] Scientific Paper No. 400.

POSITIVE AND NEGATIVE PHOTO-ELECTRICAL PROPERTIES OF MOLYBDENITE AND SEVERAL OTHER SUBSTANCES.[7]

By W. W. Coblentz.

[ABSTRACT.]

The paper gives a description of new observations on positive and negative spectrophotoelectrical reactions in molybdenite, silver sulphide, etc., as dependent upon temperature as well as magnitude and direction of the current through the crystal. It is shown that for radiation of wave-lengths less than 0.7μ the photoelectrical reaction, in a certain sample of molybdenite, is positive or negative depending upon the magnitude and direction of the current through the crystal. In three appendices data are given: (1) on a frequency relation in the sensitivity bands of molybdenite, (2) a survey of the general spectrophotoelectrical properties of substances and, (3) on thermal radiophonic signalling apparatus.

METALLOGRAPHIC ETCHING: I: FOR COPPER.[8]

By Henry S. Rawdon and Marjorie G. Lorentz.

[ABSTRACT.]

The investigation of metallographic etching reagents in progress at the Bureau of Standards is illustrated by a detailed account of the etching of the various forms of copper. This metal was chosen as the first type for consideration on account of its industrial importance as well as because its behavior is typical of many of the important industrial alloys of copper, *i.e.*, the brasses and bronzes.

Two general types of etching as defined by the characteristic appearance of the etched surfaces are described. These are designated as " plain " and " contrast." While many reagents as a rule give but one type of etched surface, it is possible to produce either type, as desired, from some reagents. In general, " contrast " etching is most suitable for microexamination at relatively low magnifications. For study of those features of structure for which high magnifications must be used, the plain uncontrasted etched surface is desired.

Oxidation is of fundamental importance in the solution of

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[7] Scientific Paper, No. 398.
[8] Scientific Paper No. 399.

copper and consequently in the etching of the metal. Many solutions which have a very slight etching action upon copper may be made to etch readily by passing oxygen through them, but solutions which have no solvent action upon copper cannot be made to etch the metal by the addition of oxygen. Ammonium hydroxide, in the absence of oxygen, has an almost negligible action upon copper. Most of the etching solutions in general use consist of an oxidizer in an acid or an ammoniacal solution. A few very powerful oxidizing agents may be used in solution without the addition of either ammonium hydroxide or acid.

In general, aqueous solutions are best for the etching of copper. In a very limited number of cases, however, alcoholic solutions appear to give better results. Typical etching reagents are described, and micrographs are given to illustrate the characteristic features of each.

THE EFFECTS OF CAL AS AN ACCELERATOR OF THE HARDENING OF PORTLAND CEMENT MIXTURES.[9]

By Roy N. Young.

[ABSTRACT.]

This paper presents the important details and results of an investigation conducted at the U. S. Bureau of Standards for the purpose of determining the relative value of Cal as an accelerator of the hardening of Portland cement mixtures. While a greater part of the paper deals with the effect of Cal on the early strengths of mortars and concretes, results of miscellaneous tests bearing upon the nature of the material and its effects on setting-time, soundness, etc., are included.

Cal is essentially an oxychloride of lime in a powdered form. It is readily decomposed by water into calcium chloride and calcium hydroxide, the property of accelerating the hardening of Portland cement being due to the former product. The chief advantage of using Cal rather than calcium chloride is the much greater convenience with which it may be handled.

The setting-time of Portland cement mixtures was hastened by the addition of Cal to an extent which is considered very desirable in certain types of concrete construction, especially floor toppings, for the reason that the finishing operation may proceed

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with much less delay. Tests on quick-setting cements indicate that such cements may be made normal by the addition of Cal. It is also shown that unsoundness may be greatly improved or entirely overcome by this treatment.

The early hardening of Portland cement mixtures is hastened by the addition of Cal. The strength of mortars was increased from 40 per cent. to 140 per cent., and the strength of concrete from 52 per cent. to 135 per cent. at the age of two days by an addition of Cal equal to 5 per cent. of the cement. Comparison tests, in which commercial calcium chloride was used as the accelerator, indicate that the general effect of Cal is practically the same as might be expected from the use of equivalent amounts of calcium chloride and hydrated lime.

No conclusions were drawn from very limited corrosion tests, but it is advised that caution be exercised in the use of Cal in concrete containing steel reinforcing if the concrete is to be freely exposed to the weather or excessive dampness.

POURING AND PRESSURE TESTS OF CONCRETE.[10]
By W. A. Slater and A. T. Goldbeck.

[ABSTRACT.]

The tests reported in this paper were carried out for the purpose of obtaining information for use in the construction of concrete ships.

In the pouring test the aim was to determine whether, with the thin shell of the concrete ship, it was possible to pour, properly, concrete of the consistency which was to be used in the construction work, constricted as was the space in the forms by the presence of large quantities of reinforcement. A slab 6 ft. square and 4 in. thick was constructed by standing the form up on one edge and pouring the concrete into the form through windows in the side at three different elevations. By means of grooves in the slabs which were provided in the making of the slab, the slab was broken into heavily reinforced beams each a foot wide and six feet long. These beams were tested to determine something of the quality of the concrete.

This test indicated that the pouring could be carried out suc-

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[10] Technologic Paper No. 175.

cessfully under the conditions of ship construction, and it showed that the concrete so obtained was of a high grade.

In the pressure test the pressure of the concrete against the forms was measured. The form used was about 17 feet high. The concrete was introduced through windows placed at intervals in the height of the form. The pressure measuring instruments were placed at various heights, and the readings of pressure taken at various intervals of time after the concrete had been placed.

The maximum pressure against the forms during the pouring of concrete was found to be equivalent to that of a liquid weighing 124 lb. per cu. ft.

The maximum pressure was found to be that due to the head of concrete existing at the end of about 40 minutes after the placing of the concrete. After that time the pressure decreased gradually in spite of an increasing head.

The Radium Content of the Rocks of the Loetschberg Tunnel. J. H. J. Poole. (*Phil. Mag.,* October, 1920.)—This tunnel, 14,536 m. in length, runs from Kandersteg to Goppenstein in the Bernese Oberland. Samples of the pulverized rock were heated to about 1100° C. with an equal mixture of sodium and potassium carbonate. The carbon dioxide evolved was absorbed in a soda-lime tube and the residual gases stored. When the decomposition of the rock was completed they were swept back into an exhausted electroscope, from the change of deflection of which the mass of radium present in the gas was inferred. The results are stated by giving the billionths of a gram of radium present in one gram of rock. This radium content is least, .8, for a specimen of quartz schist and greatest, 6.5, for talc felspar schist. When the determinations are averaged for all the specimens of the same kind of rock quartz sandstone is seen to lead the list with a content of 4.3, while anhydrite is lowest with 1.1. The northern end of the tunnel was the poorer in radium. The general mean for all the rocks examined was 2.2.

In the St. Gothard tunnel a very large temperature gradient at one end was coincident with a high radium content of the rocks traversed. In the Loetschberg tunnel neither the thermal gradient nor the radium content varied greatly along the portion examined.

G. F. S.

NOTES FROM THE RESEARCH LABORATORY
EASTMAN KODAK COMPANY.*

IMAGE CONTRACTION AND DISTORTION ON PHOTO-GRAPHIC PLATES.[1]

By F. E. Ross.

THIS is a comprehensive résumé of what has been done pre-viously and of recent investigations. The author deals mainly with the gelatine strains and stresses, and the tendency, when part of a photographic plate has dried and an adjacent region remains wet, for the wet gelatine to be drawn toward the dry portion, and the influence of this tendency upon the resultant relative positions of adjacent images or parts of images, especially when there is any comparatively large mass dry before the adjacent portions, such as the image of the inner portions of the solar corona during a total solar eclipse. The bearing of these distor-tion effects upon photographic tests of the " Einstein Theory " made during total solar eclipses is taken up; also, the effect upon photographs of double stars and star clusters. It may also in-fluence measurements of the distance apart from adjacent lines in photographs of spectra.

A CHART METHOD OF TESTING PHOTOGRAPHIC LENSES.[2]

By L. E. Jewell.

[ABSTRACT.]

THE method discussed consists in photographing with the lens under test a chart composed of a large number of similar units, each unit being a radially sectored circular chart, the sectors being alternately black and white, and approximately 5° in angular diameter. The interpretation of the photographs of this chart in terms of the lens aberration is discussed.

PHOTOGRAPHIC PHOTOMETRY AND THE PURKINJE EFFECT.[3]

By F. E. Ross.

[ABSTRACT.]

THE increase in diameter of a star's image is proportional to the logarithmic increase of exposure time, and it is proposed that when this is measured with an artificial star the coefficient of increase shall be called the *astrogamma* because of its analogy with the factor which is termed *gamma* in photographic work. Both gamma and astrogamma are dependent upon the wave-length, and photometric measurements of stars made photographically must take into consideration this variation of gamma and astrogamma with wave-length. These effects are considered in the paper. Some results obtained with long exposure where the light source is very weak are also given. The theoretical considerations involved are dealt with here.

ON THE RELATION BETWEEN PHOTOGRAPHIC DENSITY, LIGHT INTENSITY AND EXPOSURE TIME.[4]

By F. E. Ross.

THE equations connecting photographic density with exposure which have been proposed by Abney, Hurter and Driffield, Elder and Channon are critically discussed. In particular certain theoretical objections to the Hurter and Driffield formula are advanced. The author proposes a new formula, the underlying idea being the separation of the grains of an emulsion into different classes, according to their sensitiveness. The thickness of the emulsion is taken into consideration, and is measured not in microns but by number of layers of grains. The mass-action equation is assumed to hold for each group. All formulæ are compared with two types of measured characteristic curves, in one of which the " toe " is prominent, in the other, it is almost absent. It is difficult to include the characteristics of " toe " and " shoulder " in any simple algebraic formulæ. These peculiarities point to the existence of secondary phenomena.

The paper concludes with a discussion of the reciprocity law, the necessity of further experimental work being emphasized. The laws of Schwarzschild and Kron are discussed and compared with the reciprocity law. Assuming Schwarzschild's law correct, two simple methods of obtaining the parameter P in the formula are given.

Home Production of Rare Carbohydrates. (*A. C. S. News Service, Bul. 275.*)—A number of carbohydrates of special nature are required in modern bacteriologic work, and up to comparatively recent times the supply of pure forms was entirely from Germany. American manufacturers have been giving attention to the matter, and it now appears that the domestic supply is ample and satisfactory. These products have to be of high purity in order to furnish the closely standardized media now employed in bacteriologic and pathologic research, and some of the procedures are elaborate and difficult, so that the products are costly. Fortunately, the amounts used in ordinary work are quite small, so that the operating cost in their use is not great.

Among the carbohydrates now available from American houses are: dulcitol, mannose, xylose, inulin, levulose and raffinose. Dulcitol is the most expensive, being quoted at about one dollar per gram. In the bulletin from which the above data are taken there is some persiflage about the source of mannose being the manna alluded to in the Bible, but of that statement the less said the better.

H. L.

Commercial Air-Transport.—The flying machine is now so familiar an object that it attracts but little attention as it passes overhead. The possibility of rapid and lofty flight with heavier-than-air machines is no longer questioned by any one. The days are past when such eminent scientists as Lord Kelvin and Simon Newcomb could express the view that such flight by any but a very small machine is impossible. Langley, to whom is due the initiative of practical aviation, worked amidst most discouraging conditions; present-day experts in the field have no need to discuss either with scientists or the public at large the practical problems of flying. Nevertheless, some disappointment is felt by many that the airplane has not been employed more extensively in the arts of peace. During the last few years we have heard much of its power as a destroying agent in war, its work in this field partaking of both dramatic and brutal features, and since the establishment of peace, or, at least, armistice, a good deal has been done in the way of sport and some little in the way of express service, principally in connection with the post office.

H. L.

Excessive Gasoline Waste. (*A. C. S. News Service, Bull. 276 C.*)—Dr. A. C. FIELDNER, Supervising Chemist, U. S. Bureau of Mines, Exp. Station at Pittsburgh, Pa., has found as result of extensive investigations that nearly one-third of the gasoline used in automobiles is wasted. The experiments were conducted to ascertain the pollution of the atmosphere of the vehicular tunnels now under construction in New York City, by motor vehicles. The experiments were made under the same conditions as apply to actual traffic. The chief cause of the waste is a too rich gasoline mixture. An improved form of carburetor should be devised, which should be practically automatic in operation. On the basis of 34 cents per gallon, American automobilists are using about $115,000,000 worth of gasoline a year, of which, according to Doctor Fieldner, about $34,000,000 could be saved by improved methods, largely in better construction and operation of carburetors.

H. L.

A New Determination of Avogadro's Constant. J. CABANNES. (*Comptes Rendus*, November 2, 1920.)—Monochromatic light from mercury vapor was sent through a mass of argon. 98.5 per cent. of the light diffused laterally by the gas was found to be polarized. On account of this it was permissible to regard the molecules of argon as spheres and to make use of the formula derived by Lord Rayleigh. This gave for the value of Avogadro's constant (6.90 ± .25) $\times$ 10^{23}. Millikan found (6.07 $\times$ 10^{23}) and Perrin from his studies of Brownian motions obtained (6.85 $\times$ 10^{23}) for this constant. It is interesting that such widely differing methods lead to such concordant results.

G. F. S.

International Atomic Weights for 1921.—The Report of the International Committee on Atomic Weights for 1920–1921 (*Jour. Am. Chem. Soc.*, 1920, xlii, 1761–1764) makes but one change in the international table; the atomic weight of scandium is now given as 45.1, instead of the old value 44.1. The atomic weights of the other 82 elements are unchanged.

J. S. H.

Reaction Between Carbon Bisulphide and Ammonium Carbonate.—This reaction has been studied by FRANÇOIS A. GILFILLAN of Yale University (*Jour. Am. Chem. Soc.*, 1920, xlii, 2072–2080). At a temperature of 160° C., these two compounds interact, and yield a mixture of ammonium thiocyanate and thiourea; the equilibrium depends upon the concentration of the reagents used, temperature, time of heating, and concentration of the hydrogen sulphide formed in the reaction.

J. S. H.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

A CHEMICAL STUDY OF FROZEN FISH IN STORAGE FOR SHORT AND LONG PERIODS.[1]

By E. D. Clark and L. H. Almy.

[ABSTRACT.]

BLUEFISH, *Pomatomus saltatrix,* and weakfish, *Cynoscion regalis,* frozen by commercial methods and stored at 15° F., when "glazed" with an ice covering, remained palatable and wholesome during storage for 16 and 13 months, respectively, but became unpalatable after 2 years. The uneviscerated weakfish were in practically the same good condition after 13 months' storage as were the eviscerated fish. Unglazed weakfish dried out rapidly and were considered unmarketable at the end of 4 months.

The changes in the chemical composition of these fish during storage were slight in most instances. In the bluefish water-soluble, coagulable, and proteose nitrogen decreased, together with the iodin number of the extracted fat, while the nitrogen of amino-acids, ammonia, and amines, and the acid value of the fat increased. In the weakfish, water-soluble and coagulable nitrogen increased at first, then decreased in all fish except the unglazed samples, in which the changes were irregular; proteose nitrogen underwent no distinctive change; amino-acid nitrogen increased slightly; increase of ammonia and amine nitrogen was marked in the glazed uneviscerated fish and but slight in the other lots; the acid value of the extracted fat increased and the iodin number decreased in all samples.

COMMERCIAL HYDRASTIS (GOLDENSEAL).[2]

By Arno Viehoever.

[ABSTRACT.]

HYDRASTIS is one of the most important domestic drugs, and is also extensively exported. Since it is a very expensive drug, its

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price per pound now being $5.70 to $5.80 for the whole drug, and $6.50 to $6.75 for the powdered drug, it is especially important that it should be in a satisfactory condition.

Thirty-two samples, both whole and ground, of Hydrastis collected in interstate trade, were examined, and, in addition, three of known origin, which had been carefully collected and washed. The results of the examination were as follows:

1. The proportion of rhizome to roots varied considerably in the samples examined.

2. The alkaloid content was found to be higher in the rhizomes than in the roots.

3. The raising of the required minimum alkaloid content to 2.75 per cent. of ether-soluble alkaloids is suggested.

4. Samples collected in interstate trade, while containing sufficient alkaloid, as required by the United States Pharmacopœia, contained rather generally amounts of mineral matter greatly in excess of that naturally present.

5. The total and acid-insoluble ash in the roots was found to be higher than in the rhizomes.

6. A maximum limit of 8 per cent. for total ash, and 3 per cent. for acid-insoluble ash is proposed.

The Spectrum of the Green Ray. A. Danjon and G. Rougier. (*Comptes Rendus*, October 26, 1920.)—Sometimes a second or two before the sun has completely set the portion of the disk still above the horizon assumes a green color. A similar effect occurs at sunrise. This is known as the "green ray." There have been two theories to account for it. Anomalous dispersion is invoked by one while by the other regular dispersion is regarded as the cause. According to the latter, the atmosphere of the earth forms a vertical spectrum of the sunlight. The blue and violet parts are absorbed in traversing the long stretches of air, and thus the green is left at one end of the spectrum and is the last color seen. One of the authors noticed before the war that the setting sun viewed through a telescope showed, under favorable conditions, a green fringe around its upper half. This was visible for the last ten minutes before sunset. Utilizing this long duration the investigators have photographed the spectrum of the green fringe. It is found to differ from the spectrum of the setting sun only in lacking the red which has been deviated by atmopsheric dispersion. No trace of anomalous dispersion appears. The experiments were conducted on the platform of Strasbourg Cathedral, France.

G. F. .S.

NOTES FROM THE U. S. BUREAU OF MINES.[*]

STRUCTURE IN PALEOZOIC BITUMINOUS COALS.

By Reinhardt Thiessen.

CONCEPTIONS of the origin, composition and general nature of coal differ so widely that to determine the real extent of actual knowledge is no easy matter. The chemist finds difficulty in attacking the chemical problems and the engineer lacks a broad basis for the study of his problems. Thus the economical and efficient utilization of coal in the industries suffers from a lack of knowledge of the composition of coal itself.

Most scientists interested in this matter appear to have had only a vague idea of the components of coal and their origin. During the past century many correct observations have been recorded, but through false or inadequate interpretations many contradictory conclusions have been drawn, resulting in great confusion. Also, the requisite knowledge of chemistry or of other sciences necessary to true interpretations was often lacking. For example, speculation as to the true meaning of the bright and dull bands which are seen in all ordinary bituminous coals, and were observed even by the earliest investigators, has led to the forming of many false theories, such as the one that these bands were due to alternating climatic changes during the period of coal formation. If geologists had known the true nature of coal they would not have made this mistake.

The Bureau of Mines, in the endeavor to clear up some of the confusion that exists and fill existing gaps in our knowledge of the composition and origin of coal, has for some years been conducting at its Pittsburgh station, a microscopic study of coal.

This work has involved the perfecting of a method for preparing the thin sections for direct observation under the microscope or for the preparation of photomicrographs. In these sections the coal is revealed in its original chemical and physical condition and natural color. Some sections have been prepared

thin enough to permit photography at a magnification of 2000 diameters. Much skill, experience, and patience are needed, however, to prepare them.

The results of the first series of observations appeared in Bulletin 38 of the bureau, entitled: " The Origin of Coal," by David White and Reinhardt Thiessen, in 1914.

The immediate cause that led the writer of this article to investigate further the composition of coal and the origin and structure of its constituents was that when an attempt was made to discover the cause of the coking or non-coking properties of coal a more exact knowledge of the nature of coal was required. Accordingly, samples were collected from representative bituminous coals in Pennsylvania, Indiana, Illinois, and Alabama, as well as various other localities in this country and in other countries. Results of this later study are presented in Bulletin 117, recently issued by the bureau, entitled: " Structure in Paleozoic Bituminous Coals," by Reinhardt Thiessen.

COAL-WASHING EXPERIMENTS AT SEATTLE STATION.

By Earl R. McMillan.

COAL seams in the Northwest are rarely free from " bone " and shale or clay partings, are nearly all folded and faulted, dip at various angles, and in some cases are badly broken. In mining seams the raw coal as it comes to the surface often contains as much as 50 per cent. by weight of waste. The Bureau of Mines experiment station at Seattle is conducting washing tests of this coal in order to improve it for commercial use. Since the process of coal-washing depends upon differences in specific gravity between the clean coal and its associated impurities, the first problem undertaken was that of determining the specific gravity of the clean coal and of each parting of impurity contained in a large number of representative seams.

It was found that the freshly mined coal is practically saturated with water, this being observed in samples varying from low-grade subbituminous up to semianthracite, all of which are found in the State of Washington. The specific gravity values determined for the cleanest particles varied from 1.28 to 1.35; in general, the higher the rank of the coal the higher the specific gravity.

The raw coal contained a relatively small proportion of free particles of clean coal, the greater proportion being bone, shale, and clay particles, with specific gravities ranging from 1.35 to 2.65. The float-and-sink method was used to determine the proportions of clean coal and of the heavier impurities, as well as the relations between their specific gravity and ash content. As in use of this method of testing, difficulty arose in obtaining accurate and consistent results, it was necessary to standardize the method by a long series of careful tests. In the standardization tests it was found that the coal must be kept saturated with water throughout in order to obtain accurate (and comparable) results. In order to test large samples quickly and accurately, a float-and-sink machine was built and, with experience, improved to a very satisfactory degree.

The prime object of the tests is to devise washing methods that will prevent loss of good coal and easily and cheaply remove the dirt. In working out this problem, coöperative studies have been made with several of the coal-mining companies and gratifying results obtained. For example, one company in the State of Washington for years has been discharging sludge into a pile recently estimated at 150,000 tons. As a result of washing tests by the Bureau engineers, the mine owners are erecting a washing plant equipped with five tables for treating the entire pile. The material now has a recoverable value of $2 per ton, or a total of $225,000.

At the plant of another coal company the raw nut coal contained 24 per cent. ash. After washing in a jig, the washed coal was found to contain 23 per cent. ash, and 15 per cent. of the feed was discharged as a washery refuse. After several days experimenting with the jig, using the float-and-sink test as a control, the ash in the washed coal was reduced to 16 per cent., with a recovery of 86 per cent.; 92 per cent. of the washed coal and 25 per cent. of the refuse floated on a 1.55 solution, the loss of good coal in the refuse being reduced from 9.3 per cent. to 3.5 per cent. of the feed. Since approximately 250 tons a day are washed on this jig, the saving amounts to about 17 tons a day, which, at $4 per ton, is worth $68, also the services of two pickers were dispensed with, effecting a further saving of $13.60 a day. The results are given in more detail in a recent report published by the bureau.

VANADIUM.

By J. P. Bonardi.

Leaching tests of a sample of roscoelite ore, conducted at the Bureau's experiment station at Golden, Colo., has shown that chloridizing roasting, followed by sulphuric acid leaching, using about 250 pounds of acid per ton of ore, and then leaching with water, will recover more than 90 per cent. of the vanadium content. Leaching with water, without the use of acid, yields only 60 to 70 per cent. of the vanadium.

On another ore consisting of vanadinite with a little descloizite, chloridizing and nitre-cake roasts, followed by water and dilute acid leach, extracted more than 90 per cent. of the vanadium. In the chloridizing roast the lead is volatized and can be recovered. Concentration experiments showed that by simple panning of −40 mesh material, with no attempt at classification, a concentrate is produced containing 11.4 per cent. V_2O_5 and 43.4 per cent. Pb, with a recovery of more than 75 per cent. of both the vanadium and the lead.

Wind Turbines. E. Weiss. (*La Nature*, October 23, 1920.)— The deliberate and scientifically executed destruction of the French coal mines by the German invaders followed by their failure to deliver coal to France as they had promised to do in the Treaty of Versailles has naturally constrained French engineers to seek to employ other sources of energy. Plans have been devised for utilizing the energy of the tides, of the waves of the sea, and of the river Rhone. At the last Paris fair a wind turbine was shown. The turbine surmounted a framework about 45 feet high. Its axis was vertical as were the blades which had a length of roughly 18 feet. By the words " Houille Azur " on the structure the title " Blue Coal " is preëmpted for wind power, just as " White Coal " is understood to mean water power. The wind turbine lends itself well to the operation of dynamos with accompanying batteries of accumulators to carry the load while the wind is not blowing. It seems likely that it may be applied also to the operation of irrigation pumps, electric furnaces, small shops and lighthouses. The design must take into account the facts that in the Paris district the longest stretch of wind calm is 60 hours and that in a year there 245 days on which the speed of the wind is 4 metres or more per second.

G. F. S.

THE FRANKLIN INSTITUTE.

(Proceedings of the Stated Meeting held Wednesday, November 17, 1920.)

PRESIDENT DR. WALTON CLARK *in the Chair.*

Additions to membership since last report, 4.

Reports of progress were presented by the Committee on Library and the Committee on Science and the Arts.

The Chairman announced that the first business of the meeting was the presentation of the Elliott Cresson Medal and recognized Mr. Charles Penrose, Chairman of the Committee on Science and the Arts, who introduced Dr. W. L. R. Emmet, to whom had recently been awarded the Elliott Cresson Medal for his contributions to the art of ship propulsion.

Mr. Penrose said:

"*Mr. President.* Due, as you know, to the generosity and constructive forethought of various gentlemen interested in the objects of the Institute, the Institute's Committee on Science and the Arts is enabled to recognize invention and discovery in physical science by means of awards and medals appropriate to the importance of the particular invention or discovery brought to its attention.

"Tonight you are asked to present the Institute's Elliott Cresson Medal to Dr. W. L. R. Emmet in recognition of his notable contributions to the art of ship propulsion.

"Founded some three-quarters of a century ago, this medal has been awarded for such inventions as the telephone, telautograph, typesetting machines, the aeroplane, and multiplex telephony and telegraphy by guided ether circuits.

"With such inventions as these it is felt that Dr. Emmet's electrical method of propelling ships takes rank.

"It would require more time than is allowed me to adequately outline his elegant and epoch-making contributions to an all-important art developed through long and intensive periods of brilliant and successful experimentation. Nor, indeed, is it necessary here as the Institute's report dealing with the subject serves well for purposes of record.

"I quote, however, the report's concluding paragraph:

"'After a careful consideration and study of Dr. Emmet's work relating to ship propulsion, the Institute is of the opinion that it deserves the highest award in its gift for the recognition of inventions of signal importance, and awards to Dr. W. L. R. Emmet the Elliott Cresson Medal in recognition of his "Notable Contributions to The Art of Ship Propulsion."'"

The Chairman presented the Medal and accompanying documents to Dr. Emmet, who expressed his thanks for the honor conferred upon him.

Dr. George A. Hoadley was then recognized and presented Messrs. G. L. Kothny and Robert Suczek, of Philadelphia, who had been awarded the Edward Longstreth Medal of Merit for their Radojet air pump.

Dr. Hoadley said:

"*Mr. President:* Two Philadelphia engineers have invented and put into successful operation a device by means of which expanding steam at a high velocity is used for the removal of air from a zone of high vacuum, a new and extensively used form of jet condenser.

"This device is called the Radojet Air Pump. It consists of two steam ejectors working in series. In the first stage a group of axially directed nozzles is used, while in the second stage steam is delivered radially through an annular nozzle, leaving it in the form of a sheet having a high velocity.

"The apparatus is small in volume, light in weight and has proved itself efficient in service.

"In recognition of the merits of this invention The Franklin Institute has awarded the Edward Longstreth Medal of Merit to Mr. G. L. Kothny and Mr. Robert Suczek, the inventors.

"I have the honor, Mr. President, to present Mr. Kothny and Mr. Suczek."

The Chairman presented the medals and accompanying documents to the inventors. Mr. Kothny expressed his thanks for the honor conferred upon him and his colleague.

Mr. Nathan Hayward offered the following resolution, which was seconded by Dr. Hoadley and passed unanimously:

Resolved, That a Committee be appointed to nominate Officers and Managers for the year 1921.

Mr. Charles Day offered the following resolution:

Resolved, That a Committee of five members of the Institute be appointed, approved by the Board of Managers, with the President and Secretary of the Institute as ex-officio members, to carry into effect the intent and purposes of the Henry W. Bartol bequest to The Franklin Institute.

This motion was duly seconded by Mr. Charles E. Bonine and unanimously carried.

The paper of the evening was presented by Dr. Charles A. Culver, of the Canadian Independent Telephone Company, Limited, Toronto, Canada, on "Guided Wave Telephony." Consideration was given to the fundamental principle and limitations involved in high frequency multiplex operation and the history of the invention and early development of this new means of communication was briefly outlined. Current practical engineering methods were discussed, including special applications to hydro-electric power line operation and train dispatching. The problem of attenuation and required power was also treated. The subject was illustrated by lantern slides and a working demonstration given of communication by means of guided wave telephony superimposed upon a physical telephone circuit. A vote of thanks was extended to the speaker and the meeting adjourned.

R. B. Owens,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, November 3, 1920.)

HALL OF THE INSTITUTE,
PHILADELPHIA, November 3, 1920.

MR. CHARLES PENROSE *in the Chair.*

The following report was presented for final action:

No. 2753: Sterilization by High Pressure. The Edward Longstreth Medal of Merit to Professor B. H. Hite, of Morgantown, West Virginia.

The following reports were presented for first reading:

No. 2712: "Sponsel" Calibrating and Gun Barrel Straightening Machine. Advisory.

No. 2760: Ankyra Ankor Bolt. Advisory.

R. B. OWENS,
Secretary.

SECTIONS.

Section of Physics and Chemistry.—A meeting of the Section was held in the Hall of the Institute on Thursday evening, October 28, 1920, at eight o'clock, Dr. George F. Stradling in the chair. The minutes of the previous meeting were read and approved.

Ludwik Silberstein, Ph.D., of the Research Laboratory, of the Eastman Kodak Company, Rochester, New York, delivered an address on " Spectrum Analysis and Its Application to the Study of Atomic Structure," which discussed the modern theories of line spectra from the viewpoints of Plank's quantum concept and Bohr's assumption of stationary orbits.

After a discussion of the paper, a vote of thanks was extended to Dr. Silberstein ; and the meeting adjourned.

JOSEPH S. HEPBURN,
Secretary.

Electrical Section.—A meeting of the Section was held in the Hall of the Institute on Thursday evening, November 4, 1920, Mr. William H. Gartley in the Chair. The paper of the evening, entitled " The Application of Radio to Navigation Problems," was presented by Admiral W. H. G. Bullard, Director, Naval Communication Service, Navy Department, Washington, D. C. Consideration was given to the application of radio telegraphy in the determination of the time and hence the longitude at sea ; in furnishing weather reports to vessels at sea and the location and presence of icebergs ; in determining the position of ships at sea, and aircraft by means of the radio direction finder ; in directing ships through narrow channels by the directive pilot cable. The application of the radio compass to determine presence of thunderstorms and forecasting their presence and approximate local direction was also described, as well as the determination of position

of ships at sea in thick weather by means of underwater radio signals. Mention was also made of the application of radio to meteorology—for the collection and distribution of synoptic reports throughout the world, of special benefit in forecasting weather for long-distance aircraft flights and consequently safety in sea flying. The subject was illustrated by lantern slides. After a brief discussion a vote of thanks was extended to the speaker and the meeting adjourned.

R. B. Owens,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, November 10, 1920.)

RESIDENT.

Mr. George E. Éwe, 353 East Walnut Lane, Germantown, Philadelphia, Pennsylvania.

NON-RESIDENT.

Dr. Charles E. Caspari, 2108 Locust Street, St. Louis, Missouri.

Mr. A. R. Stevenson, Jr., 6 Union Street, Schenectady, New York.

ASSOCIATE.

Mr. Walter C. Hess, 1813 Erie Avenue, Philadelphia, Pennsylvania.

CHANGES OF ADDRESS.

Mr. T. Lees Bartleson, 305 West 19th Street, Wilmington, Delaware.

Mr. J. Vaughan Bostwick, 426 Montgomery Avenue, Haverford, Pennsylvania.

Mr. Sterling H. Bunnell, 103 Park Avenue, New York City, New York.

Mr. R. E. Glover, 1022 Jackson Street, Wilmington, Delaware.

Mr. F. W. Hartzel, 932 Cheltenham Road, Philadelphia, Pennsylvania.

Mr. F. P. Howe, 242 South 17th Street, Philadelphia, Pennsylvania.

Mr. J. P. Jefferson, P. O. Box 645, Santa Barbara, California.

Mr. M. C. Kennedy, Vice-President Pennsylvania Railroad Company, Broad Street Station, Philadelphia, Pennsylvania.

Mr. Charles W. G. King, 125 Linden Avenue, Rutledge, Delaware County, Pennsylvania.

Mr. George MacLean, 208 West 88th Street, New York City, New York.

Mr. B. B. Milner, in care of Frazer and Company, 30 Church Street, New York City, New York.

Mr. S. Peacock, Wheeling Steel Building, Wheeling, West Virginia.

Colonel Samuel Reber, 27 Van Dam Street, New York City, New York.

Dr. George D. Rosengarten, 115 Broadway, Point View, Miami, Florida.

Mr. Frederick W. Salmon, Montour Falls, New York.

Mr. C. P. Schlicke, 31 Plaza Street, Brooklyn, New York.

Mr. H. R. Van Deventer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pennsylvania.

Mr. W. Chattin Wetherill, Department of Mechanical Engineering, University of Pennsylvania, Philadelphia, Pennsylvania.

NECROLOGY.

Mr. **Daniel Christy,** 1214 South 5th Street, Philadelphia, Pennsylvania.
Mr. **Charles A. West,** 14 Fulton Street, Boston, Massachusetts.

LIBRARY NOTES.

PURCHASES.

CLARK, M.—Determination of Hydrogen Ions. 1920.

DEAN, B.—Helmets and Body Armor in Modern Warfare. 1920.

HULTGREN, A.—Metallographic Study of Tungsten Steels. 1920.

LEMPFERT, R. G. K.—Meteorology. No date.

MARSHALL, A.—Dictionary of Explosives. 1920.

SHERBONDY, E. H. and G. D.—Text-Book of Aero Engines. 1920.

VON ROHR, M.—Geometrical Investigation of the Formation of Images in Optical Instruments. 1920.

WINN, W.—Timbers and Their Uses. 1919.

WITHAM, G. S.—Modern Pulp and Paper Making. 1919.

GIFTS.

Adams Company, Catalogue No. 58. Dubuque, Iowa, 1920. (From the Company.)

Alabama Geological Survey, Bulletin No. 22, Petroleum Possibilities of Alabama, 1920. (From the Survey.)

Alberger Pump and Condenser Company, Bulletin No. 29. New York City, N. Y., 1920. (From the Company.)

Alexander Bros., Eleven Pamphlets. Philadelphia, Pa., 1920. (From the Company.)

American Cast-Iron Pipe Company, Prepared Joint Electric Cast-Iron Pipe. New York City, N. Y., 1920. (From the Company.)

American Institute of Electrical Engineers, Transactions, Vol. xxxviii. New York City, N. Y., 1919. (Given by Dr. R. B. Owens.)

American Locomotive Company, Catalogue No. 10050. New York City, N. Y., 1920. (From the Company.)

American Tool Works Circular No. 4. Cincinnati, Ohio, 1920. (From the Company.)

Anti-Corrosion Engineering Co., Water That Won't Rust. New York City, N. Y., 1920. (From the Company.)

Association Francaise pour l'Avancement des Sciences, Conferences 1918–1920. Paris, France, 1920. (From the Association.)

Automatic Fuel Saving Company, Automatic Combustion Control. Philadelphia, Penna., 1920. (From the Company.)

Baldwin Chain and Manufacturing Company, General Catalogue, Edition F. Worcester, Mass., 1920. (From the Company.)

Barnes, William O., The Barnes Precision Cutter Grinder. Leominster, Mass., 1920. (From Mr. W. O. Barnes.)

Benjamin Electric Manufacturing Company, A Big Thought in a Big Way. Chicago, Illinois, 1920. (From the Company.)

Bernitz Furnace Appliance Company, Clinker-Proof Furnace Walls. Boston, Mass., 1920. (From the Company.)

Black & Decker Manufacturing Company, Electric Air Compressors. Baltimore, Maryland, 1920. (From the Company.)

Blaw-Knox Company, Transmission Towers. Pittsburgh, Penna., 1920. (From the Company.)

Bond, Charles Company, Catalog F-10. Philadelphia, Penna., 1920. (From the Company.)

Brooke Tool Manufacturing Company, Limited, Brooke Tools. Birmingham, England, 1920. (From the Company.)

Brown Instrument Company, Catalogue. Philadelphia, Penna., 1920. (From the Company.)

Bruce Peebles and Company, Current Dynamos and Motors. Pittsburgh, Penna., 1920. (From the Company.)

Busch-Sulzer Bros. Diesel Engine Company, Two-Cycle Type C Diesel Engines. London, England, 1920. (From the Company.)

Butterfield and Company, Division Catalogue 18. Derby Line, Vermont, 1920. (From the Company.)

California State Mining Bureau, Mines and Mineral Resources of Sierra County. San Francisco, 1920. (From the Bureau.)

Carnegie Institute of Technology, General Catalogue, 1920. Pittsburgh, Penna., 1920. (From the Institute.)

Carpenter, George B., & Co., Catalogue No. 110. Chicago, Ill., 1920. (From the Company.)

Chicago Belting Company, Catalog and Belting Reference Book. Chicago, Ill., 1920. (From the Company.)

Chicago Flexible Shaft Company, The Melting Pot. Chicago, Illinois, 1920. (From the Company.)

Chicago, Pneumatic Tool Company, Bulletin 504. New York City, N. Y., 1920. (From the Company.)

Detroit Hexagon Drill Company, Three Pamphlets. Detroit, Michigan, 1920. (From the Company.)

Diamond State Fibre Company, Diamond Fibre and Its Uses. Bridgeport, Penna., 1920. (From the Company.)

Driver-Harris Company, Case Carbonizing. Harrison, N. J., 1920. (From the Company.)

Du Pont Chemical Company, Catalog. Wilmington, Delaware, 1920. (From the Company.)

Duquesne Burner Service Company, Combustion Unit. Pittsburgh, Penna., 1920. (From the Company.)

Dwight Manufacturing Company, Catalogue No. 10. Chicago, Illinois, 1920. (From the Company.)

Economy Electric Devices Company, Bulletin No. 70. Chicago, Ill., 1920. (From the Company.)

Engineer Company, Modern Practice in Combustion Control. New York City, N. Y., 1920. (From the Company.)

Eureka Battery Company, Catalogue No. 10. Chicago, Ill., 1920. (From the Company.)

Fairbanks Company, Catalogue 916. New York City, N. Y., 1920. (From the Company.)

Galvanizing Corporation of America, Electro Galvanizing. Brooklyn, N. Y., 1920. (From the Corporation.)

Golden Anderson Valve Specialty Company, Catalogue No. 20. Pittsburgh, Penna., 1920. (From the Company.)

Greenfield Machine Company, Catalogue No. 7. Greenfield, Mass., 1920. (From the Company.)

Hammond Steel Company, Catalogue No. 20. Syracuse, N. Y., 1920. (From the Company.)

Hays School of Combustion, Opportunities for the Combustion Expert. Chicago. Illinois, 1920. (From the School.)

Holophane Glass Company, Inc., Book No. 340. New York City, N. Y., 1920. (From the Company.)

Huyck, F. C. & Sons, Two Related Industries. New York City, N. Y., 1920. (From F. C. Huyck & Sons.)

Hydro-Electric Power Commission, Twelfth Annual Report for the Year Ending October 31, 1919. Toronto, Canada. (From the Commission.)

Ilg Electric, Ventilating Company, Heating Problems. Chicago, Illinois, 1920. (From the Company.)

Iron and Steel Institute, Journal Vol 101. London, England, 1920. (From the Institute.)

Jackson Compressor Company, Rotary Motion. Denver, Colorado, 1920. (From the Company.)

Jeffrey Manufacturing Company, Bulletin Nos. 288 and 309. Columbia, Ohio, 1920. (From the Company.)

Jellett, Stewart A., Company, The Final Test. Philadelphia, Penna., 1920. (From the Company.)

Jones A. A., & Shipman, Ltd., Better Tools. Toronto, Canada, 1920. (From Jones & Shipman.)

Lehigh University, Catalogue. Bethlehem, Penna., 1920. (From the University.)

Link-Belt Company, Book No. 224, 345 and 352. Chicago, Illinois, 1920. (From the Company.)

Locomotive Superheater Company, Bulletin T-6, Data Book for Engineers. New York City, N. Y., 1920. (From the Company.)

Mason Regulator Company, Catalogue No. 60. Boston, Mass., 1920. (From the Company.)

Metric Metal Works, Bulletin No. 114. Erie, Penna., 1920. (From the Works.)

Michigan Central Railroad Company, Seventy-fourth Annual Report for the Year Ending December, 1919. (From the Company.)

Moltrup Steel Products Company, Catalogue No. 1. Beaver Falls, Penna., 1920. (From the Company.)

National Aniline and Chemical Company, Information Regarding "National Service and Products," New York City, N. Y., 1920. (From the Company.)

National Lamp Works of General Electric Company, Twenty-four Bulletins. Cleveland, Ohio, 1920. (From the Company.)

New York Board of Water Supply, Fourteenth Annual Report. New York City, N. Y., 1920. (From the Company.)

Niles-Bement-Pond Company, Right Line Radial Drill. Philadelphia, Pa., 1920. (From the Company.)

Packard Electric Company, Bulletin Nos. 207–208. Warren, Ohio, 1920. (From the Company.)

Pangborn Corporation, Bulletin No. 50. Hagerstown, Maryland, 1920. (From the Corporation.)

Pennsylvania Railroad Company, Seventy-third Annual Report, 1919. Philadelphia, Penna., 1920. (From the Company.)

Permutit Company, General Bulletin No. 101. New York City, 1920. (From the Company.)

Philippine Bureau of Civil Service, Twentieth Annual Report. Manila, 1920. (From the Company.)

Philippine Director of Education, Twentieth Annual Report. Manila, 1920. (From the Director.)

Portland Cement Association, Concrete Work in Cold Weather. Chicago, Ill., 1920. (From the Association.)

Pratt and Whitney Company, Precision Machine Tools. Hartford, Conn., 1920. (From the Company.)

Reed Prentice Company, Lathes and Radial Drilling Machines. Worcester, Mass., 1920. (From the Company.)

Reliance Spring and Manufacturing Company, Booklet for Every Purpose. Brooklyn, New York, 1920. (From the Company.)

Rhode Island Public Utilities Commission, Eighth Annual Report, 1919. Providence, R. I., 1920. (From the Commission.)

Smith, T. L., Company, Bulletin Nos. 405, 406, 409A, and 410. Milwaukee, Wisconsin, 1920. (From the Company.)

Smithsonian Institution, Annual Report for 1918. Washington, D. C., 1920. (From the Institution.)

South Bend Lathe Works, Text-Book No. 4. South Bend, Indiana, 1920. (From the Works.)

Southern Railway Company, Twenty-sixth Annual Report, Richmond, Va., 1919. (From the Company.)

Sprague Electric Works, Bulletin No. 44553.1. New York City, N. Y., 1920. (From the Works.)

Staffords National Service, Who's Who in Philadelphia in Wartime. Philadelphia, Pa., 1920. (From the Editor.)

Standard Scale and Supply Company, Catalog No. Y.190. Pittsburgh, Penna., 1920. (From the Company.)

Stewart, Frank H., Electric Company, Catalogue No. 22. Philadelphia, Penna., 1920. (From the Company.)

Strong, Carlisle and Hammond Company, Catalogue No. 22, Section C, and Catalogue No. 8-G. Cleveland, Ohio, 1920. (From the Company.)

Temple University, Annual Catalogue, 1920. Philadelphia, Pa. (From the University.)

Triumph Ice Machine Company, Bulletin 516, Cincinnati, Ohio, 1920. (From the Company.)

Truscon Steel Company, Buildings and Steel Windows. Youngstown, Ohio, 1920. (From the Company.)

Uehling Company, Bulletin 111, New York City, N. Y., 1920. (From the Company.)

United States Commissioner of Patents, Annual Report for 1919. Washington, D. C., 1920. (From the Commissioner.)

U. S. Department of Commerce, Commerce and Navigation of the United States for 1919. Washington, D. C. (From the Department.)

University of Nebraska, Fiftieth Annual General Catalogue. Lincoln, Nebraska, 1920. (From the University.)

Wahl, H. R., Company, Bulletin D-1. Chicago, Illinois, 1920. (From the Company.)

Waltham, Massachusetts, Second Inaugural Address of Hon. George R. Beal, Mayor, and Annual Reports for 1919. Waltham, Massachusetts, 1920. (From the City of Waltham.)

Whitcomb Blaisdell Machine Tool Company, Lathes, Planers. Worcester, Mass., 1920. (From the Company.)

Wisconsin Electric Company, Time and Labor Saving Devices. Racine, Wisconsin, 1920. (From the Company.)

BOOK NOTICES.

CATALYSIS AND ITS INDUSTRIAL APPLICATIONS. By E. Jobling, A.R.S.C., B.Sc., A.I.C. Second edition, small 8vo, viii-134 pages, index and 12 illustrations. Philadelphia, P. Blakiston's Son & Co. $3.75, net.

Since 1836 when Berzelius coined the term catalysis for a series of mysterious chemical actions, the problems presented by these actions have been the subject of continual and extensive investigations, and a vast number of phenomena added to the few that were known to the Swedish chemist. As a matter of fact, a catalytic action, still practically unexplained, though very familiar, was announced in 1832, when Döbereiner published in the first number of the *Annalen*, his discovery of the peculiar action of manganese dioxide in determining the decomposition of potassium chlorate.

A large literature, most of it summarized in books, now exists concerning all types of these actions. The book in hand is a brief treatment of some of the more important industrial applications of the principals of catalytic action. Fifteen pages are devoted to a discussion of the general conditions favoring and interfering with these actions. The formal definition given is that of Ostwald: "A catalytic agent is that material which affects the velocity of a chemical reaction without appearing in the final products." Another definition, somewhat more pedantic perhaps, is: "A catalyst is a substance that increases the specific velocity of a reaction without stoichi-

ometric participation therein." It is pointed out in the book that a catalyst sometimes undergoes a physical change in the course of its action, the instance given being that of manganese dioxide which passes from a crystalline to an amorphous condition when used in the preparation of oxygen from potassium chlorate, but in this case the material is strongly heated, and this may be the cause as much as any specific action as a catalyst.

Many of the common industries are now dependent on catalytic methods for proper and economic operation, and the more important of these are described in concise and convenient form. The general style, printing and arrangement of the book are commendable.

HENRY LEFFMANN.

DICTIONARY OF EXPLOSIVES. By Arthur Marshall, A.C.G.I., F.I.C., F.C.S., Chemical Inspector, India Ordnance Department. 8vo. xiv–159 pages. Philadelphia, P. Blakiston's Son & Co. $3.75, net.

The extensive experience of the author of this book and his success in presenting the literature of it in highly satisfactory form, prevents any doubt as to the value of the present compilation. It presents brief statements of the composition of the several hundred explosives that are now known, enumerated alphabetically by their trade names and also classified according to their uses. The classes are: coalmine, blasting, high, miscellaneous and propelling. The resources of language have been strongly drawn on for the many names that have been coined to indicate the changes that have been rung on the comparatively few mixtures and compounds that are available for use as explosives. The reviewer has been a little puzzled by an allusion to an explosive termed " imperialite," the name being derived from that of the Marquis Imperiali, who used his private means in experimenting on explosives. He started a factory for the manufacture of some, and on the first day of its operation an explosion killed five workers. He rebuilt the factory and the day after it was re-started it blew up again, and the marquis was killed. The puzzling item in the account is that Marshall states that its history is that of the explosive that we meet " in the comic papers." There must be a joke here, but the reviewer is not " on to it."

The book contains a large amount of information, and will be of much use to chemists who cannot afford the more expensive works on the subject. The reviewer is moved to ask why there is no recent authoritative and comprehensive work on explosives emanating wholly from American sources, especially from the experts of the great du Pont works.

HENRY LEFFMANN.

NOTES ON CHEMICAL RESEARCH: AN ACCOUNT OF CERTAIN CONDITIONS WHICH APPLY TO ORIGINAL INVESTIGATION. By W. P. Dreaper, O.B.E., F.I.C. Second edition, small 8vo, xv–195 pages, no index. Philadelphia, P. Blakiston's Son & Co. $2.50, net.

As the author said in the preface to the first edition, modern science is based on the record of past investigation. He might have added that a feeling of gratitude should actuate all who practice a profession or a science which will induce each one to labor as far as in him lies to increase the stock of

knowledge. The bulk of the book is devoted to a free and extensive presenta-
tion of the methods of research and the apparatus to be used, taking the word
in its widest sense to mean the literature and laboratory facilities. There is,
as might be expected, a good deal of philosophic discussion which represents
the author's views, entitled to serious consideration for he has given much
thought to the subject, but concerning which there is room for difference
of opinion.

The reviewer is most interested in the chapter on the course of training
for the student, and hoped that some attention would be given to the earlier
training, especially an expression of opinion as to the comparative value of
the old university course in the so-called " humanities " and the modern
so-called " practical " course. Dreaper, however, considers only that part
of the students' training which concerns the later work, when specializing in
the science. He refers to the " Heuristic " method of teaching without giving
any details. The reviewer confesses ignorance of this method, but does not
suppose that it consists in studying the properties of matter while bathing, as
the word suggests. The author says that the period between the ages of 17
and 23 is a critical one. Unquestionably, but so is the period between 12 and
17. " Just as the twig is bent, the tree's inclined." Nothing is said about the
training in language. The reviewer believes in the study of the classics in
school life and the study of French and German in college life for all students
intending scientific work, especially physics and chemistry.

With the great mass of Mr. Dreaper's statements, the reviewer has
no quarrel.

HENRY LEFFMANN.

A TEXT-BOOK OF ORGANIC CHEMISTRY. By E. DeBarry Barnett, B.Sc.
    (Lond.), A.I.C. Lecturer in Organic Chemistry, Sir John Cass Technical
    Institute. Small 8vo, xii–369 pages, index and 15 illustrations. Phila-
    delphia, P. Blakiston's Son & Co. $5.00, net.

A neatly printed book on good paper giving a survey of the field of organic
chemistry in the form now usual in smaller manuals. It opens with the
statement that " organic chemistry is best defined as the chemistry of the
compounds of carbon " and proceeds to point out that the substances included
in descriptive organic chemistry were called organic because they were regarded
as formed only under the influence of " vital force," but that this idea was
exploded when Wöhler, in 1828, obtained urea from inorganic sources. This
is the usual phraseology. It is not quoted here to disapprove it, but to suggest
that it would be an interesting matter to investigate the origin of the applica-
tion of the term organic to a special field of chemistry. It is hardly true that
the basis of the division of chemistry into its two familiar branches was
" completely exploded " by Wöhler's discovery. Every chemist feels that
some line of demarkation exists between the mineral kingdom and the living
one, though it is true that in the highest levels of philosophy the unity of
nature impresses itself upon us and we realize that " all are but parts of one
stupendous whole." Indeed, the author says that the division is merely " a
matter of convenience."

So far as the mass of text of the book is concerned, no unfavorable

criticism is to be recorded. A very large amount of information is presented in a convenient and vivid form, and the work will serve very well the purposes of the beginner in the study of its field.

One of the most interesting and striking features of the book is the advice as to the more elaborate literature to be consulted. About four pages are devoted to this phase, the greater portion of it to recommending German books, some in English translation but many in the original. It is doubtful if a book published in the United States would venture on this method. England has suffered vastly more than the United States from German methods of warfare, yet English scientists have never lost their heads and have always recognized the value of German work, especially in chemistry.

<div style="text-align:right">Henry Leffmann.</div>

National Advisory Committee for Aeronautics.

Report No. 82, Airplane Stress Analysis. Preprint from Fifth Annual Report, 70 pages, illustrations, diagrams, quarto. Washington, Government Printing Office, 1920. This is a handbook of airplane stress analysis and was prepared in 1917, for the Chief Constructor of the Navy, Admiral D. W. Taylor, U. S. N. It was primarily intended to aid those who had to make for the U. S. Government estimates of airplane stress and factors of safety. The text, written by Dr. A. F. Zahm, comprises three parts: Part I, being introductory, presents briefly the mechanics of materials and of elementary structural members; Part II treats of airplane wing stresses; Part III treats of body stresses. Part IV, written by Mr. L. H. Crook, gives in detail the numerical solutions of the illustrative practical problems presented in the text, and by use of the methods and equations therein formulated. Finally, in Part V, prepared by the authors jointly, are assembled the tables, formulas and descriptive diagrams illustrating the text; also the graphical solutions of many of the standard stress problems given in the text.

Report No. 89, Comparison of Alcogas Aviation Fuel with Export Aviation Gasoline, 14 pages, illustrations, quarto. Washington, Government Printing Office, 1920. Aviation alcogas, prepared by the Industrial Alcohol Co., of Baltimore, Md., for trial by the Navy Department and by the latter submitted to the Bureau of Standards for test, was a mixture apparently of about 40 per cent. alcohol, 35 per cent. gasoline, 17 per cent. benzol, and 8 per cent. other ingredients. This is not the alcogas prepared for commercial or passenger car use. The exact composition and methods of manufacture are a trade secret. The tests made for the Navy Department consisted in a direct comparison, in a 12-cylinder Liberty engine, between alcogas and standard "X" (export grade) aviation gasoline with respect to maximum power attainable, and fuel consumption with the leanest mixture giving maximum power. The tests were made in the altitude laboratory at the Bureau of Standards, where controlled conditions simulate those of any altitude up to 30,000 feet. The speed range covered was from 1400 to 1800 revolutions per minute and the altitude range from ground level to 25,000 feet. Two series of comparisons were made, one with 5.6 compression ratio pistons and one with 7.2 compression ratio pistons.

PUBLICATIONS RECEIVED.

U. S. War Department: Annual Reports, 1919, 6 volumes, illustrations, plates, maps, 8vo. Washington, Government Printing Office, 1919–1920. Contents: Vol. I, Part I.—Reports of the Secretary of War; Chief of Staff; Adjutant General; Commander-in-Chief, American Expeditionary Forces; Director General; Judge Advocate General, Quartermaster General, Chief Signal Officer. Vol. I, Parts II and III.—Report of the Surgeon General. Vol. I, Part IV.—Reports of the Chief of Ordnance; Chief of Militia Bureau; Chief of Coast Artillery; Chief of Construction Division; Director of Tank Corps; Director of Chemical War Service; Director of Real Estate Service, Board of Ordnance and Fortification; Director of National Defense; Chief of Motor Transport Corps; Chief of Transportation Service; Chief of Field Artillery; Military Parks. Vol. II.—Reports of the Chief of Engineers. Vol. III.—Reports of the Chief, Bureau of Insular Affairs, 1919; Governor of Porto Rica 1919; Philippine Commission 1918.

U. S. Department of Mines: Bulletin No. 184, The Manufacture of Sulphuric Acid in the United States, by A. E. Wells and D. E. Fogg, 216 pages, illustrations, plates, 8vo. Washington, Government Printing Office, 1920. Monthly Statement of Coal-Mine Fatalities in the United States, June and July, 1920, by W. W. Adams, 2 pamphlets, 8vo. Technical Paper 259, Production of Explosives in the United States during the Calendar Year, 1919, with notes on coal-mine accidents due to explosives and list of permissible explosives tested to May 31, 1920, by William W. Adams, 31 pages, illustrations, 8vo. Washington, Government Printing Office, 1920. Technical Paper 266, Coke-oven Accidents in the United States during the Calendar Year, 1919, by William W. Adams, 25 pages, 8vo. Washington, Government Printing Office, 1920.

Ontario Department of Mines: Bulletin No. 882, 29th Annual Report, being Vol. XXIX, Part III, 1920, 95 pages, illustrations, plates, maps, 8vo. Toronto, King's Printer, 1920.

U. S. Department of Agriculture: Bulletin No. 882, Manufacturing and Laboratory Tests to ·Produce an Improved Cotton Airplane Fabric, by Fred Taylor and D. E. Earle, 48 pages, illustrations, 8vo. Washington, Government Printing Office 1920.

Pratt Institute Free Library: Technical Books of 1919. A selection, 28 pages, 16mo. Brooklyn, N. Y., Pratt Institute Free Library, 1920.

Ajax Metal Company: Ajax Metal Products; White Metal Alloys, Bronze and Brass Ingots, Bearings and Castings. Philadelphia, Ajax Metal Company, 1920. 38 pages, illustrations, quarto.

Atomic Weight of Thulium.—C. JAMES and O. J. STEWART of New Hampshire College have redetermined the atomic weight of thulium, and obtained a value of 169.44 (average of five determinations). The ratio determined was that of thulium chloride $TmCl_3$ to silver (*Jour. Am. Chem. Soc.,* 1920, xlii, 2022–2023).

J. S. H.

CURRENT TOPICS.

The National Advisory Committee for Aeronautics has just issued a bulletin received from its Paris office, in which the conditions and possibilities of commercial air service are extensively discussed. The air offers some great advantages as a commercial route. No survey nor construction work is needed, nor are land damages or rights of way to be considered, unless, indeed, legislation should take a hand in the matter. Grade-crossing accidents, head-on and tail-end collisions are not impossible, but reasonable care will avoid such, for air lanes may be established similar to sea lanes that have been laid down for transatlantic travel.

According to the aeronautical correspondent of the *London Times*, a question asked in the House of Commons brought out a statement that within twelve weeks over 2000 passengers have been carried by airplane in England, and that the service between London and the Continent is now being operated with the regularity of an express train, and has realized lately a small profit.

Mr. Frank Searle, General Manager of the Airco Company, presents in the bulletin under consideration a review of the problems of regular air transport. The Airco Company can be considered a real commercial aerial transportation company, as it carries about 1000 passengers per month between London and Paris. There are many problems to be solved before commercial airplane service can be placed on a basis as safe and satisfactory as existing methods of transportation.

Among the serious difficulties with the early airplanes was the need of constant attention and repair. Looked at from a commercial point of view, these older airplanes were capable of earning money only about an hour and a half during the twenty-four, the rest of the time the machine was in its shed, and insurance and overhead charges were running on without break. To-day the machine is called on to do five times more work than formerly. No data are at hand as yet by which to determine exactly the average life of the commercial aero-engine, but there are motor omnibuses now running satisfactorily in London, the engines of which are ten years old. If these can stand the strains of travel, it seems reasonable to suppose that engines can be constructed for airplanes which will have at least as long a life. The absence of grinding wear and tear, so serious and inevitable a condition of earth transport, stands out conspicuously as a factor in the London-Paris air service. It could not be expected that the comparatively frail construction of these planes could stand for a day's rough and tumble work, but they rush to and fro in the air

without any appreciable damage for a limited time. Small renewals and repairs are constantly required, but these are not of serious moment in connection with the problem. Repairing by night seems to offer especial advantages. If a commercial machine is scheduled to do five hours work per day, there will be nineteen hours for keeping it in trim. A night shift of mechanics now works regularly at Croydon.

The speed of flying machines is an important factor in determining their practical value. A transporting apparatus which can easily make 100 miles per hour, taking only five hours to make a round trip which with boat or train would require twenty hours, is in a field by itself.

Designs and construction of commercial machines will have to be made matters of specific engineering investigation. The problem is different from that presented in war or sport. The question of overhaul and repair must be kept always in view. Take the question of motor, for example. If the motor of a given machine needs repair, it will be a great waste if the whole machine must go into the shop for some days. A reserve of engines should be provided, and the planes so constructed that with but little delay the substitution can be made. A commercial plane must therefore be designed which will permit of the whole motor being taken out without difficulty.

Mr. Searle thinks that the fast passenger traffic will be soon represented by two types of craft. One will be a simplified plane, somewhat of the type in use on the London-Paris service known as "Airco 16." The other should be larger, with capacity, say, for eight persons. Both, he thinks, should be single engine machines.

The latter view is a matter of controversy, but it seems certain that, from the point of view of handling and maintenance, the commercial one-motor is preferable. One point, however, is that of safety, for a two-motor machine may avoid a forced landing. Mr. Searle's answer to this is that the single engine should be constructed like the "wonderful one-hoss shay," it may wear out but can never break down. In exemplification of his views, Mr. Searle refers to the experiences with engines now used on the London-Paris service. Much of the trouble with them is due to the gears between the engine and propeller, which, for good aerodynamic reasons, it is true, cause the propellers to revolve at a lower speed than the engine. Such gears, Mr. Searle advises, should be eliminated, and a direct drive installed. There are, indeed, all sorts of minor troubles connected with the existing installation of motors in airplanes, but the plane taken as a whole, as a machine developing a certain amount of power, very rarely gives trouble when it is in proper trim. When the detailed improvements indicated by modern experience have been made, the chance of a breakdown should be remote, and the single engine machine should, for some time at least, run for short stages with

a risk of failure so low as to be practically negligible. It is unwise to make great sacrifices to lightness. The fundamental point is that the motor has to keep running to earn the money required. Therefore, even if it is a little on the heavy side, the manager will be content if it will do its work with the least trouble and overhauling. The Continental air-express service has a staunchly built six-cylinder motor, which stands up well to its work; in the words of one pilot, " it practically never lets one down." Big aero-motors are now wanted, developing a lot of power and doing it as a routine matter. Above all, they must be simple, readily accessible in all their working parts and easy to install and remove.

Much discussion has been held lately as to the substitution of metal for wood in airplane wings. This substitution should be made slowly, but it seems likely that an increasing use of metal will be noted as time goes on.

An international system by which the methods of packing and the types of machines are uniform will be necessary before extensive substitution of airplane transport of freight can compete with the methods now in use.

The question of transport over boundaries will be one of great importance and difficulty. All surface systems are easily controlled by the countries through which they pass, but air travel is far less easily supervised. Low flying machines are generally amenable to control, but in fogs air transport may be carried on without any suspicions by those on the land, and it will not be long before very high flights are possible, and these can be made at night at high speed, so as to defy any present methods of supervision. Night-flying service is, indeed, being seriously discussed, but not a secret one. It is proposed to have the lines of travel indicated by special lights, so that a pilot, flying low, can pick his way and be helped in adhering to the compass course. There are now methods known for the construction of lights that will act automatically for long periods, lighting themselves at night and extinguishing themselves in the morning.

All machines should be fitted with wireless telephone service, which will be of great use in passing through fog. Aviators frequently soar above the fog and steer by means of the compass alone.

There is little doubt that before long the distances between important points will be reduced by fast air-service to very small amounts expressed in hours.   H. L.

The Valency of Photo-electrons and the Photo-electric Properties of Some Insulators. M. J. KELLY. (*Phys. Rev.*, October, 1920.)—The method employed as long ago as 1911 by Colonel Millikan for studying the charges upon droplets was again used. The two horizontal plates of a condenser are about 1.5 cm. apart. The air between them is enclosed and is maintained at a constant temperature in order to avoid convection currents. Sulphur was

heated to 150 C. in a special atomizer. At that temperature it is a pale yellow liquid and can be easily atomized. By the instrument a group of droplets is produced. These fall owing to their weight, and some pass through holes in the upper condenser plate, thus getting into the air space between the two plates of the condenser. Here they are illuminated and are observed through a telescope with high magnification. The observer selects a suitable drop and follows its motion. It falls with very small speed. If, however, it has an electric charge and if in addition the two condenser plates are oppositely charged, then, besides its weight, another force acts on it, *viz.*, the force resulting from the interaction of its charge with the field of force between the plates. It may go up instead of falling as before and in general its speed will be different. From a knowledge of the constants of the drop, of its speed, and of the difference of potential between the plates it is possible to calculate the electrical charge on the drop. The author used a P.D. of about 7000 volts.

In the case of sulphur the drops were always found to have a static charge. They sublimed rapidly, so rapidly that a drop after 30 minutes required 28 seconds to fall just as far as it fell in 8.2 seconds at the beginning of the series of observations. The lengthening of the time was due to the dwindling size of the sphere. To avoid this error the walls of the enclosed chamber were encrusted with flowers of sulphur. After several days the air attained a relative humidity of 100 per cent. in terms of sulphur vapor and the drops could no longer evaporate.

The motion of a droplet was studied, then the observer opened a shutter and let a beam of ultra-violet light fall on it until a change of speed showed that one electron or more had been emitted. The shutter was then closed and the speed of the drop again determined. The shutter was reopened, another change of speed obtained, and so on. " Some drops were kept under observation for two hours ; .57 separate emissions were observed on one drop and over 500 emissions were observed under good experimental conditions and calculated." In all cases except two the emission was found to consist of a single electron. In the two unusual cases it consisted of two electrons. With shellac every one of the 800 emissions observed consisted of a single electron. " This is rather interesting, especially in the case of shellac in which there are complex molecules made up of a large number of atoms."

Previous investigations have shown that ionization by X-rays, by gamma rays, by beta and alpha particles, as well as in the photo-electric effect in mercury when acted on by ultra-violet light consists in the emission of a single elementary charge. The significance of Mr. Kelly's work lies in showing that in insulators where there is a dearth of free electrons (evidenced by the small electrical conductivity) the same rule holds that in ionization one electron, and one only, is set free.   G. F. S.

Electrification by Impact. HAROLD F. RICHARDS. (*Phys. Rev.*, October, 1920.)—In the production of electricity by the rubbing of one substance by another not only is there intimate contact produced, but friction also comes into play. Owing, perhaps, to the superposition of these two actions, the data of frictional electricity are somewhat erratic and a consistent theory is still to be framed. The purpose of this investigation is to study the effect of intimate contact of a metal with an insulator with no complication from friction.

An ebonite disk with its surface horizontal was let fall upon a horizontal brass disk. The charge developed upon the latter by the impact was measured by a tilted Wilson electroscope. The brass and the ebonite disks were given surfaces as flat and as smooth as possible. Between impacts radium was used to discharge the ebonite disk. The brass always acquired a positive charge and these charges were of the same order of magnitude as those produced by friction. The ebonite disk fell from different heights and thus struck the brass cylinder while moving with different speeds. In general the higher this speed the greater the charge developed. It was found that after repeated impacts the charge at a certain velocity was greater than at the beginning of the series of experiments. This may well have been due to the flattening out of the ebonite surface by which more intimate contact was produced. A variable condenser was joined to the brass anvil and determinations of the charges developed were made when the capacity varied. The charge was found to depend in no way on the capacity of the brass disk. Furthermore, the greater the weight on the falling disk, the greater the charge produced. When the upper disk was lowered gently upon the lower one a slight charge of .02 E.S.U. was caused. The addition of as much as 25 pounds to the ebonite disk while it was resting on the brass caused no increase in this small charge.

A second set of experiments was carried out in which an ebonite sphere was hurled vertically upward and struck the lower surface of a brass disk. The connection between speed of impact and charge developed is similar to that holding in the case of the impact of two disks. A glass ball and a zinc plate were also used in all combinations. There seems to be no relation between the electrical energy developed and the mechanical energy lost during impact.

A thorough revision of the experimental data of frictional electricity is needed in order to disentangle the discordant and contradictory congeries of observations made during the last two centuries. Mr. Richards has made a very promising beginning in this work.   G. F. S.

INDEX TO VOL. 190.